COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

December, 1946

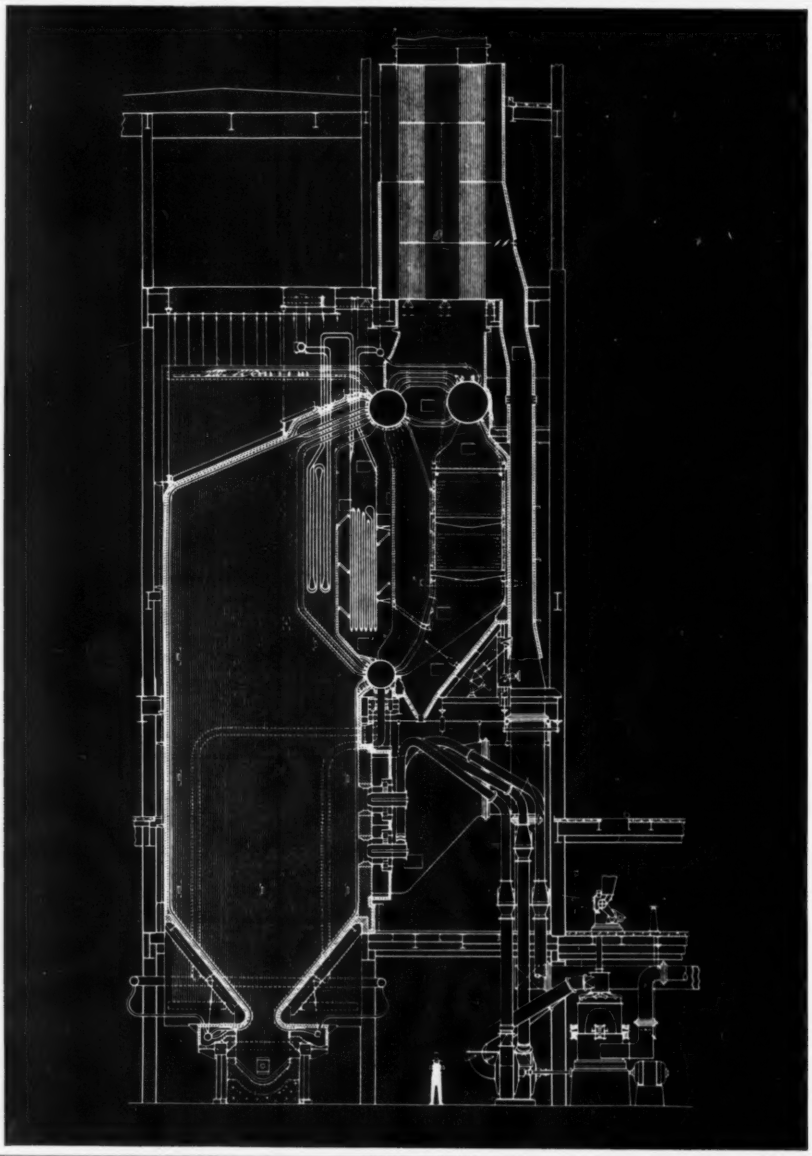
Photo by Mario Scacheri

Industrial power scene in upstate New York

Second Outdoor Plant Built in Arkansas ▶

A.S.M.E. Annual Meeting ▶

Furnace Temperature Control for Large Steam-Generating Units ▶



COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME EIGHTEEN NUMBER SIX

CONTENTS

FOR DECEMBER 1946

FEATURE ARTICLES

Second Outdoor Plant Built in Arkansas .... *by R. E. Hansen* 32

A.S.M.E. Annual Meeting—

Horizontal Cyclone Burner; Determination of Moisture Content of Coal by Means of Pulverizer Heat Balance; Application of Coal-Burning Equipment; Fuel Reserves; Factors in Smoke Abatement; Further Graphitization Studies Reported; Corrosion-Erosion of Boiler-Feed Pumps and Regulating Valves; Internal Corrosion of Furnace and Boiler Tubes; Effect of Repeated Acid Cleaning on Boiler Metal; Steam Turbines for High-Powered Combatant Ships; Flue-Gas Recirculation 37

Furnace Temperature Control for Large Steam-Generating Units .... *by Otto de Lorenzi* 49

Progress in Transformation of Basic Fuels .... *by P. C. Keith* 55

EDITORIALS

Pipe Line Disposition 31

Engineers in Public Life 31

DEPARTMENTS

Review of New Books 63

Advertisers in This Issue 64

JOHN L. WILLIAMSON, *General Representative*

ALFRED D. BLAKE, *Editor*

THOMAS E. HANLEY, *Circulation Manager*

Published monthly by COMBUSTION PUBLISHING COMPANY, INC., 200 Madison Ave., New York 16

A SUBSIDIARY OF COMBUSTION ENGINEERING COMPANY, INC.

Frederic A. Schaff, President; Charles McDonough, Vice-President; H. H. Berry, Secretary and Treasurer.

COMBUSTION is sent gratis to engineers in charge of steam plants from 500 rated boiler horsepower up and to consulting and designing engineers in this field. To others the subscription rate, including postage, is $2 in the United States, $2.50 in Canada and Great Britain and $3 in other countries. Single copies: 25 cents.

Issued the middle of the month of publication

Publication office, 200 Madison Ave., New York CCA Member of the Controlled Circulation Audit, Inc.

Printed in U. S. A.

EDITORIAL

Pipe Line Disposition

The coal strike brought to a focus pending action on disposition of the "Big Inch" and the "Little Inch" pipe lines over which the War Assets Administration has pondered for months, despite numerous offers for their operation, and in the face of opposition from competitive fuel interests. Had an early decision been made, these lines, which so well served one emergency, might have alleviated to some degree apprehensions in certain localities during the latest fuel crisis.

The temporary permit just issued to the Tennessee Gas & Transmission Company (not a bidder) to operate these lines until April 30, 1947 for the transportation of natural gas from Texas to sections of Indiana and Ohio was an emergency measure and does not necessarily affect their final disposition. It is reported that approximately one hundred fifty million cubic feet of gas daily will be handled shortly, although the estimated combined capacity of the two lines, if certain conversions in pumping equipment were made, is said to be from two to two and a half times this amount. This quantity of gas, while substantial, would displace only a relatively small part of the coal burned in the districts served, and a still smaller part of that burned under power boilers, if any; but it does provide a competitive fuel.

Whether the ultimate use of the pipe lines will involve transportation of natural gas or oil, and whether they will serve the Eastern Seaboard, the present terminus, is a matter that should be definitely decided before the interim arrangement expires next April. The Federal Power Commission has just announced the appointment of an Industry Advisory Committee to assist the Commission in allocating natural gas supplies becoming available as a result of the temporary permit for the utilization of the "Big Inch" and "Little Inch" lines, and at the same time, has directed the disposition of the gas supplies pending determination of their allocation.

These pipe lines represent a vast wartime expenditure by the Government, which was fully justified by the service rendered at that crucial period in our oil deliveries; but viewed in the light of the discounts under original costs that have been necessary in disposing of ships and other surplus properties, the WAA must be prepared to consider pipe-line bids that are greatly under initial costs. The essential thing is to put them to permanent peacetime use as soon as possible so that the public may benefit thereby. In fact, the House Surplus Committee of the Seventy-Ninth Congress has lately gone on record as recommending the prompt sale of these lines, not alone in the public interest but also to save the government fourteen thousand dollars a day in maintenance and stand by costs.

It is to be expected that Congress, shortly after it convenes in January, will strive to adopt measures aimed at precluding a repetition of the coal situation the country has just passed through. However, judged by past experiences, it would perhaps be presumptuous to infer that any measures likely to be passed would definitely assure against future interruptions in the nation's coal supply. Therefore, prudence dictates that, where possible, provision be made in the design of new steam-generating units for burning alternate fuels without involving extensive alterations. Not that there is any likelihood of coal being supplanted as the basic fuel for steam generation, but ability to use an alternate fuel is an insurance against shutdown due to lack of fuel, as well as an economic weapon in an era of rising prices.

Engineers in Public Life

That engineers take a more active part in civic affairs has long been discussed and advocated before engineering societies. Nevertheless, except in isolated cases, little progress appears to have been made. From the national standpoint, this is attested by the fact that only two members of each branch of Congress are from the engineering profession, and it is probable that a survey of state legislatures would reveal a comparable situation. Some reasons for this, as well as responsibilities that should be assumed by engineers, were discussed at the Keynote Luncheon of the recent A.S.M.E. Annual Meeting where the Hon. Carl Hinshaw, representative from California and himself an engineer by training, was the principal speaker.

According to Mr. Hinshaw and other discussors, the engineer's training seldom includes the broader aspects of political science and a liberal education. He is inclined to follow his profession ardently to the exclusion of outside interests. Furthermore, few engineers have mastered the art of public speaking; many are too shy, and certainly most engineers are too modest about their accomplishments.

On the other hand, the mechanical age which engineers have created demands engineering leadership in many aspects of public affairs. This does not necessarily imply taking up politics as a career, but it does mean active participation in community affairs by the individual and group expressions on the broader problems, where the engineer's practical knowledge and ability to translate facts honestly should win confidence and respect. Since the community is a unit of society and the states and nation are summations of these units, such participation should ultimately lead to engineers accepting their public responsibility in city councils, in state legislatures and in the Congress of the United States to a far greater extent than has been apparent in the past.

Second Outdoor Plant Built in Arkansas

A new plant, the Cecil Lynch Station, built to serve the industrial area near Little Rock, Ark., is approaching completion. Outdoor features incorporated are similar to those at Harvey Couch Station, completed in 1943. It contains a gas-fired boiler rated at 325,000 lb per hr, and the turbine-generator, located in a penthouse on roof of the condenser room, is reached by a gantry crane through roof hatches. Rated maximum output is 31,250 kw, with steam inlet conditions 850 psig, 900 F. Cooling towers supply condensing water, and make-up water is from wells.

By R. E. HANSEN

Mech. Engr., Ebasco Services Inc.

ARKANSAS Power & Light Company serves electricity in a large portion of the state of Arkansas, including the cities of Little Rock, El Dorado, Hot Springs, Helena, and Pine Bluff. Relatively small steam installations in each of these cities date, except for a 10-mw unit at Little Rock, to before 1925. Two hydroelectric plants on the Ouachita River provide 65 mw of capacity, but relatively little energy.

For many years, the Company has operated under an interconnection agreement with Louisiana Power & Light Company and Mississippi Power & Light Company. The most important source of energy for the three companies has been the Sterlington Steam-Electric Station in northeastern Louisiana, adjacent to the Monroe gas field. An extensive 110-kv transmission system covers the three-state service area, and also connects with New Orleans Public Service, Inc., and with surrounding non-affiliated power companies. During the war the four companies formed an important part of the Southwest Power Pool, with headquarters in Little Rock and extending into Texas, Oklahoma, Kansas, Nebraska and Missouri.

Despite an extension to Sterlington and completion of the Harvey Couch Steam-Electric Station in southwestern Arkansas, both in service by 1943, peak loads on the Arkansas-Louisiana-Mississippi-New Orleans group have been little below system capability during the

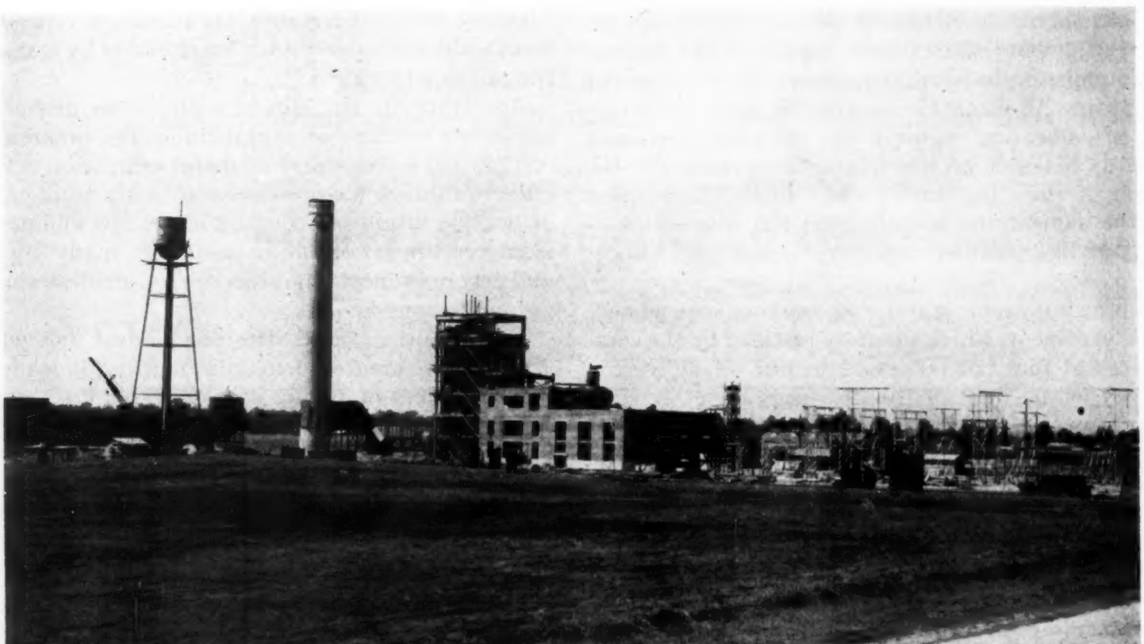


Fig. 1—General view showing oil-storage tanks, cooling tower behind elevated water tank, elevated oil service tank, power plant and step-up substations

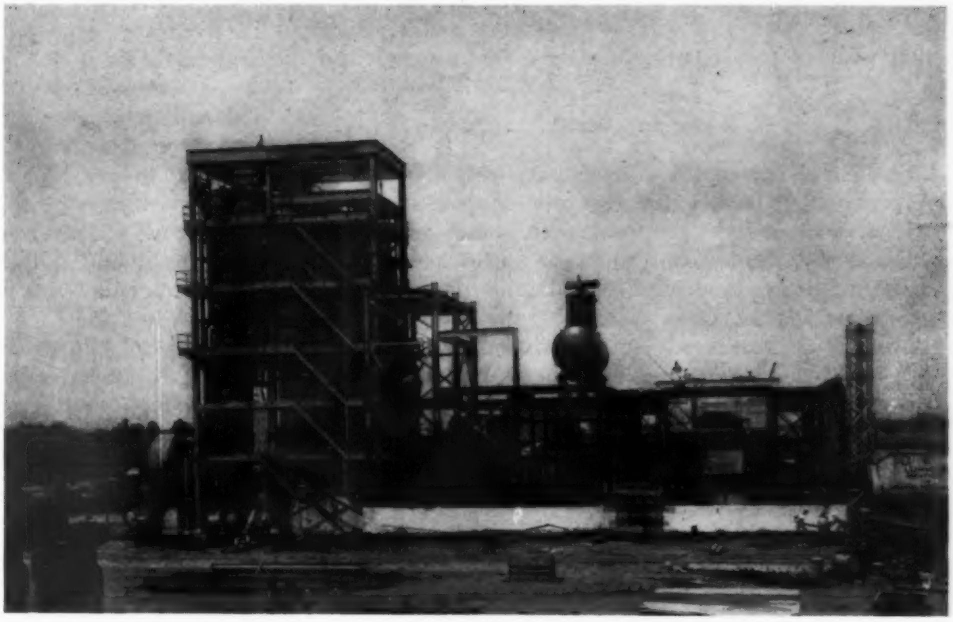


Fig. 2—Construction view showing boiler drums and tubes in place, deaerator in position and condenser being moved into building

war years. Decision was made early in 1945 to build a new plant in the important Little Rock area, where increased local loads appeared to justify a nearby source of energy. Location of the Harvey Couch Station, more than 100 miles from Little Rock, had been predicated on utilizing low-cost gas fuel locally available. Further extension there or at Sterlington would have required considerable transmission-line investment.

Selection of Site

After considering all requirements, such as water and gas supply, electrical transmission, and transportation facilities, it was decided that a location a short distance northeast of Little Rock was the most suitable for a steam-electric station. The site selected lies across the Arkansas River from the city and necessitates river crossings for gas-supply lines. Such lines are subject to some hazard during floods, but by installing two crossings, well separated, and curving each downstream to permit settling in case the stream bed is eroded, and providing oil standby at the plant, dependable fuel supply was assured. The site is believed adequate for four units, or about 120 mw.

The plant tract is adjacent to the St. Louis Southwestern Railroad right-of-way, and close to highways. River crossings of the Big and Little Inch pipelines are just east of the plant, and there is a pumping station on the north bank. A transmission line connecting Dixie Substation at Little Rock with Woodward Substation at Pine Bluff originally passed about 1000 ft from the site; this line has been looped into the plant, giving 110-kv connections from the station to the two cities mentioned.

The new plant is named Cecil Lynch Steam-Electric Station, in honor of Cecil S. Lynch, Executive Vice President of Arkansas Power & Light Company. Operation is scheduled for the spring of 1947. A general view of the development is given in Fig. 1, but unfortunately the turbine-generator penthouse and gantry crane were not in place at the time this photograph was taken.

Fuel Supply

Two eight-inch natural-gas lines cross the Arkansas River, connecting with present mains of the Arkansas-Louisiana Gas Company some ten miles from the plant. Fuel oil is received by tank car, and stored in two 10,000-bbl tanks; one 1000-bbl elevated service tank supplies the burners. Eventual use of pulverized coal, bituminous or semi-anthracite, is provided for, but no coal equipment has been installed for this.

Building Design

Station building investment has been kept low by adoption of semi-outdoor design. This has been worked out over a number of years, as described in the April 1946 issue of COMBUSTION. Arrangement is similar to that of Harvey Couch Station, shown on page 32 of that issue. An architect's sketch of Cecil Lynch Station was also presented therein, on page 37. One difference in the two designs is that in Lynch Station it was decided to house the warehouse and certain other facilities in a part of the main building rather than in a nearby standard steel building.

The steam generator is completely outdoors except for an enclosed firing aisle; a concrete slab covers the top of the boiler. Draft fans and air heater, with weatherproof casings, are on separate foundations at grade, behind the boiler. The condenser room is enclosed, with turbine-generator on roof, protected by a small penthouse. Roof hatches in the latter permit use of a 25-ton outdoor gantry crane, running on tracks along the top of the condenser room walls. Auxiliary bay and control room lie between turbine and steam generator.

Foundation consists of a concrete slab approximately at grade. Superstructure is structural-steel frame with brick walls. Windows are provided as required, for light and natural ventilation, assisted by roof ventilators and fans. Electrical equipment, including transformers and circuit breakers, both for delivery of power output

to transmission lines and for supply of electric auxiliaries in the plant, is outdoors.

Fig. 2 is a construction view of the plant showing boiler, minus casing, on left, deaerator in middle, and turbine pedestal inside the condenser room at right.

Water Treatment

All well water used for station purposes, amounting to approximately two cubic feet per second, is given treatment that includes aeration, continuous cold-process lime-alum softening, and filtration. Boiler make-up is further subjected to zeolite softening and evaporation before entering the main stream of feedwater. The evaporator was furnished by Lummus Company, and much of the other water-treating equipment by Permutit Company.

heater will supply air to the burners at around 360–370 F when burning gas or oil. Steam is washed by a bubble-type washer before passing to the superheater. With feedwater at 375 F, anticipated performance at maximum rating is 81.7 per cent efficiency with gas and 85.3 per cent with oil.

The superheater is of the two-stage interbank Elesco type and steam temperature is maintained constant down to 200,000 lb per hr rating by a superheater bypass damper which may be operated either manually or automatically, by a quartz-rod thermostat sender. Special attention is given the design of damper operating linkage in order to keep moving parts as much as possible out of the path of hot gases.

Combustion control equipment, supplied by Hagan Corporation, includes a master controller regulating combustion to give constant steam pressure. A flue-gas flow controller operates the inlet damper on the induced-draft fan, and furnace draft is regulated by a controller operating inlet vanes on the forced-draft fan. Fuel supply can be controlled by regulating valves; automatic shutoff valves are also provided to operate in case of fan failure. Selection may be made between manual and automatic operation of each control.

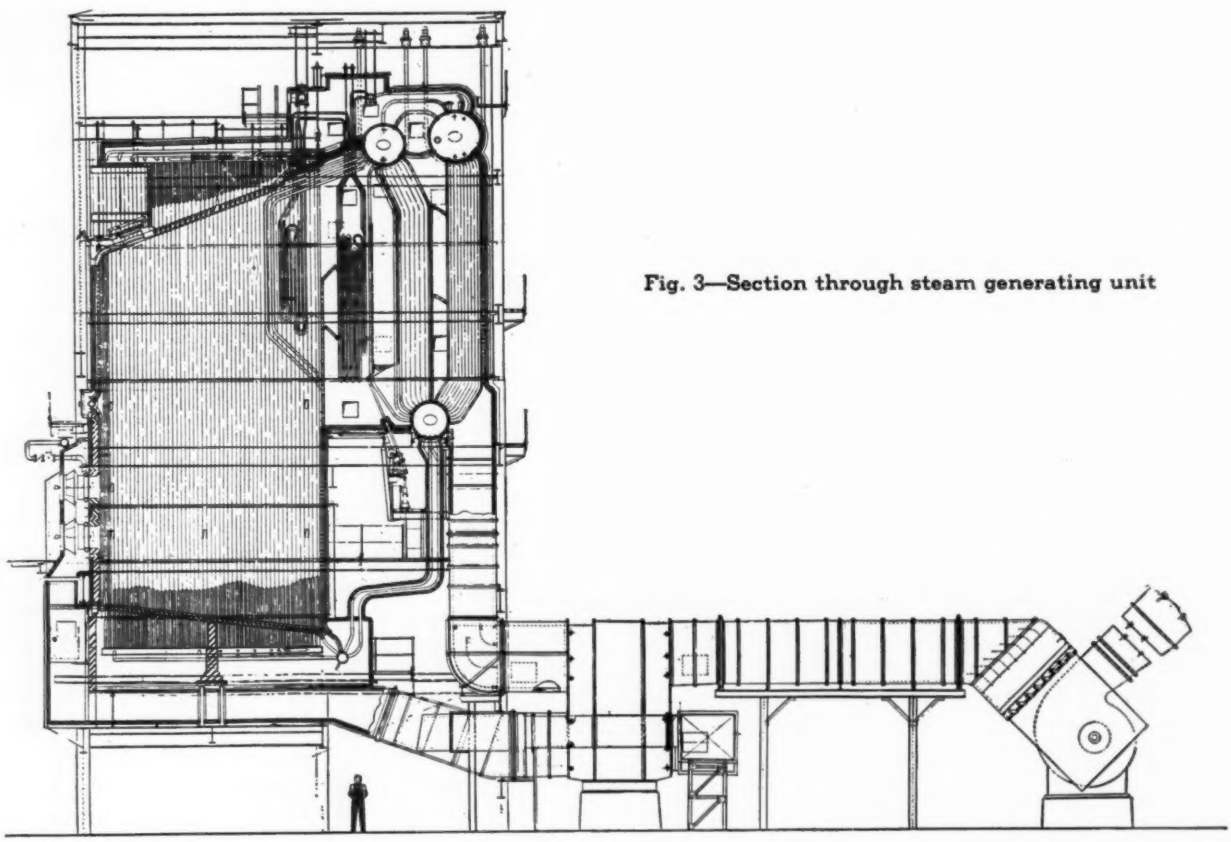


Fig. 3—Section through steam generating unit

Steam Generator

One steam generator is installed for the initial unit. This is a Combustion Engineering Company three-drum bent-tube type designed for 325,000-lb per hr steam output, with steam conditions at the superheater outlet 920 psig and 905 F. Six Peabody gas-and-oil burners fire the boiler at present, but the design is worked out for possible future operation with pulverized coal, either bituminous or Arkansas semi-anthracite. Provision is made for installation of a dust separator in case coal is employed. A Ljungstrom regenerative-type air

Forced-draft fan has inlet-vane control for improved light-load efficiency, while induced-draft fan has the simpler inlet damper control. The latter exhausts to a brick-lined reinforced-concrete stack, with 12-ft minimum inside diameter, 150 ft high.

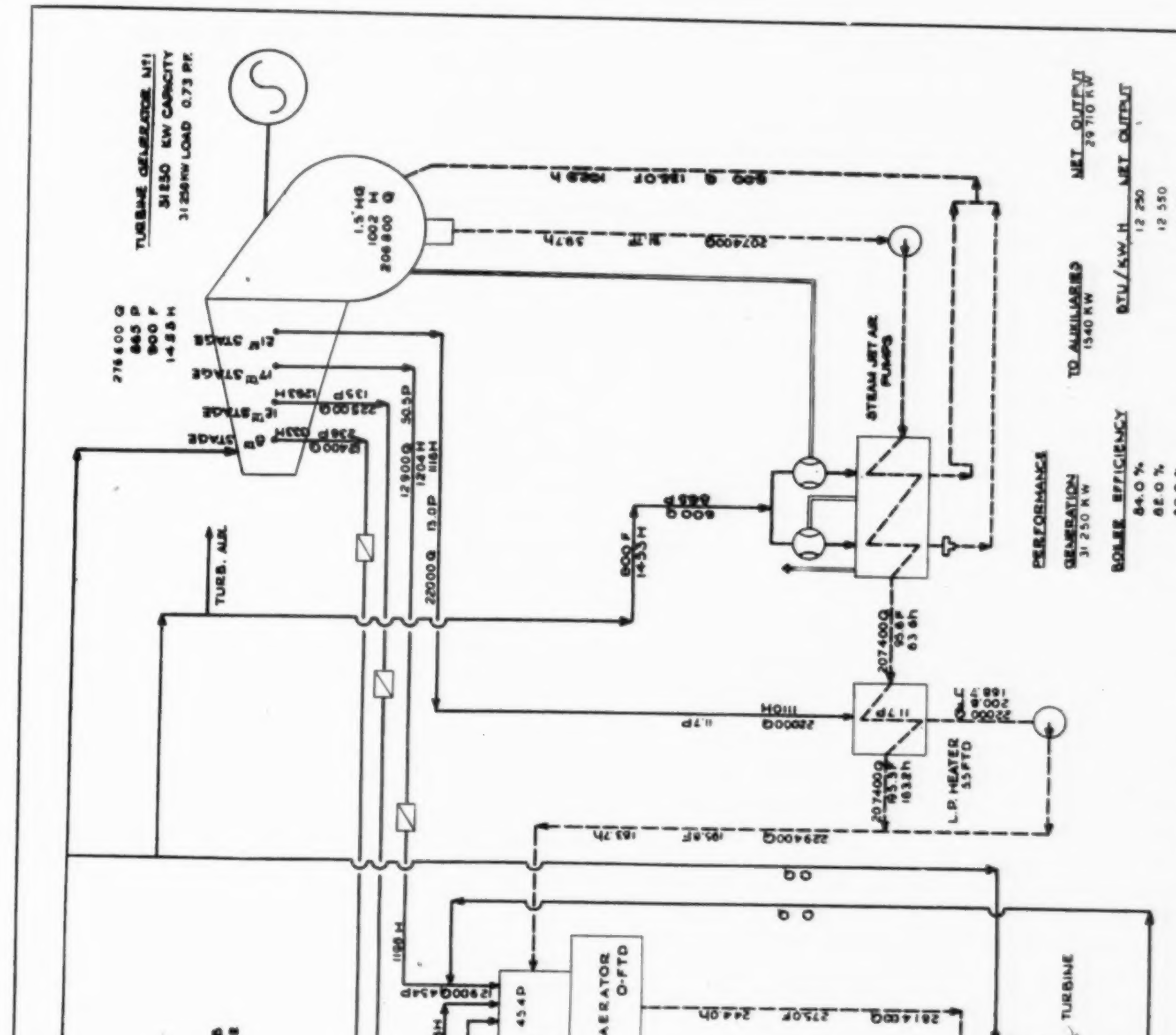


Fig. 4—Station heat balance diagram for generation at 31,250 kw, 1.5 in. Hg back pressure

Turbine-Generator

The turbine is a Westinghouse 3600-rpm 26-stage impulse-reaction machine of the single-cylinder type. Nominal rating is 25,000 kw, with maximum 31,250 kw. Steam conditions at inlet are 850 psig, 900 F, and expected average back pressure 1.8 in. of mercury absolute.

The generator is a nominal 30,000-kw 0.7-pf unit, with hydrogen cooling. By raising hydrogen pressure to 15 psig it will be possible to carry 48,000 kva. This extra generator capacity will permit carrying much of the reactive load locally, raising the power factor on transmission lines serving the area.

Excitation is by a direct-connected 155-kw exciter and pilot exciter, which are provided with a separate closed air-cooling system.

Condenser

The Lummus 24,800-sq ft two-pass non-divided water-box condenser is rated 230,000,000 Btu per hour. Tubes are arsenical copper, 0.875 in. diameter and 23 ft effective length, rolled into Muntz-metal tube sheets. Expansion is provided for by spring supports, and the exhaust neck of the condenser is welded to the turbine. The hot-well volume is 320 cu ft.

A single Allis-Chalmers horizontal circulating pump placed in the condenser room delivers 63.5 cfs, including 62 cfs for condenser and the remainder for service requirements, including generator-hydrogen and exciter-air coolers. The pump is driven at 500 rpm by a 600-hp splash-proof induction squirrel-cage motor. Two Allis-Chalmers condensate pumps, each adequate for full-load operation of plant, are driven by 75-hp drip-proof induction motors.

Cooling Tower

Although the plant is relatively close to the Arkansas River, condensing water is supplied from a cooling tower. Mechanical-draft towers perform well in the Southwest, and their employment often entails considerable savings in construction cost, by permitting wider choice of plant sites. Cecil Lynch Station is on high ground, requiring only moderate protection against extreme flood levels. Cost of substructure for river-cooled plants, particularly that of the intakes where flood-rise is high, is often considerable.

The possibility of utilizing ground water for direct cooling was studied. Such water would be disposed of after passage through the condenser, either to the river or to disposal wells. This would provide water at relatively constant temperature throughout the year, adding slightly to plant capacity during the peak summer season. It is understood that in a few instances, "water collectors" placed in gravel-beds adjacent to rivers supply water in volume approximating that required for one condenser. Assuming smaller amounts available, a combination system using a supplementary cooling tower could be used, resulting in some fuel saving. However, because of uncertainties as to the amount of water obtainable, and the effect on local water table of prolonged withdrawals at a high rate, it was decided to employ cooling towers, with well water for makeup and service requirements only.

A Marley 16-cell induced-draft tower was selected; this is 145 ft long by 63 ft wide and 25 ft high. California redwood is used throughout, with copper nails, brass bolts, and Teco timber connectors. Eight welded-frame stainless-steel-covered fans are driven by Wagner 40-hp 1800-rpm totally enclosed motors. Cooling capacity is 65 cfs, from 105 F to 90 F when wet-bulb temperature is 76 F.

Heat Balance

Pumps deliver condensate to inter- and after-condensers of the two-stage, twin-element, steam-jet air ejector. About 600 lb per hr of 850-psig steam is condensed and returned to the condenser hotwell. The low-pressure closed heater is next in line, after which condensate, augmented by low-pressure heater drips, enters an Elliott vertical deaerating heater. The deaerator receives steam bled from turbine, vapor from evaporator, and drips from evaporator and intermediate-pressure heater, the latter including cascaded high-pressure drips. The evaporator and all closed feedwater heaters are of Lummus manufacture.

Two Worthington horizontal split-casing boiler feed pumps are installed. The one normally used is driven by a 3560-rpm 700-hp Allis-Chalmers drip-proof induction motor. The spare pump is driven by 3560-rpm 700-hp 850-psig Worthington-Moore two-stage turbine, exhausting into the deaerator. Feedwater is pumped from the deaerator through intermediate- and high-pressure heaters to the boiler, entering the latter at 377 F. A diagram, showing conditions at full load with 1.5 in. of mercury back pressure, is given in Fig. 4.

Electrical Equipment

Generator leads are connected to one Westinghouse 15-kv, 3000-amp oil circuit-breaker having interrupting rating of 1000 mva, and with solenoid closing mechanism. It is tied to a 13-kv outdoor bus, from which leads are taken to three 3-phase, 15-mva step-up transformers supplied by Pennsylvania Transformer Company. The transformers may have their rating increased to 20-mva each at some time in the future, by installing forced air cooling.

High sides of the transformers are connected to the 110-kv bus from which transmission lines extend to Dixie Substation north of Little Rock and Woodward Substation near Pine Bluff. Each line is connected through one Westinghouse oil circuit-breaker rated 115-kv, 600-amp, with interrupting rating of 1000 mva.

Two Wagner station-service transformers are connected to the generator leads at 13.8 kv, each capable of delivering 2500 kva for direct supply to large motors at 2400 voltage. There are three Pennsylvania transformers each capable of delivering 500 kva from the 2400-volt auxiliary bus to small 480-volt motors. Requirements for 120- and 208-volt current are supplied by two transformers of the same make, each delivering 75 kva from the 2400-volt bus.

Auxiliary switchgear includes nine sections of air circuit-breakers, rated 5 kv, with 100 mva interrupting capacity.

Engineering and design of the plant was by Ebasco Services Incorporated, who also supervised construction work.

A.S.M.E. ANNUAL MEETING

THE Sixty-Seventh Annual Meeting of the American Society of Mechanical Engineers surpassed previous records of attendance with a registration of more than 4400. The technical program consisted of approximately 150 papers and talks, many of which were related to power matters. Because of space limitations only those having reference to steam power are contained in the following report.

Horizontal Cyclone Burner

The first paper at the Monday evening Power and Fuels Session, by **A. E. Grunert, L. Skog** and **L. S. Wilcoxon,** reported on the installation of a horizontal cyclone burner handling crushed coal in one of the steam-generating units at the Calumet Station of the Commonwealth Edison Company, Chicago. This installation has been operating since September 1944, following earlier experimental tests on a pilot plant at the Barberton Works of Babcock & Wilcox Company. The principles underlying this method of burning coal are as follows:

If crushed coal is admitted tangentially to a cylindrical burner in a stream of air at sufficiently high velocity, the particles of coal will be thrown to the surface of the cylinder and will be carried in the air stream along the wall of the cylinder in the form of an increasing-pitch helix until the energy of the entering stream of air has been dissipated. If, in addition to the primary air, sufficient secondary air for complete combustion of the coal is admitted in a path parallel to the primary air and coal, and at a correspondingly high velocity, and if the temperature is sufficiently high to promote and maintain combustion, the volatile matter will first be distilled off and burned, after which the carbon will be burned and the ash left. Provided the fusing temperature of the ash is lower than the temperature obtained on combustion it will be in a molten state as slag. This slag will coat the inside of the burner, and if the axis of the latter is inclined the molten slag will drain toward the low point from which it can be removed continuously. Movement of the slag on the surface of the burner, due to its viscosity, is very much less than the velocity of the entering air, and this provides an intense scrubbing action by the high-velocity air on the coal particles entrapped and moving with the film of molten slag. The result is extremely high combustion rates.

The unit at Calumet Station consists of a 150,000–180,000-lb per hr radiant-type boiler with an 8-ft diameter water-cooled cyclone located at the front of and at the bottom level of the furnace. The rear wall and throat of the slightly inclined cyclone burner are formed by a section of the front wall of the furnace. A continuous slag-tap opening is located in this wall at the bottom of the burner. Primary, secondary and tertiary air is supplied at between 30 and 40 in. of water pressure. The secondary and tertiary air ducts are connected tangentially to the cylindrical entry ports and crushed coal enters tangentially at the front of the cyclone with the primary air. The coal burned is high-volatile Central Illinois bituminous of low ash-fusing temperature.

Long-term tests involving the burning of nearly 56,000 tons of coal containing 12 to 13 per cent ash, showed better than 80 per cent of the ash in the coal recovered as molten slag with a corresponding decrease in the fly ash in the discharge gases. Efficiencies of 85 to 87 per cent were attained at maximum capacity and the weighted average of auxiliary power was 68.6 kwhr per ton of coal burned.

It was pointed out that, despite the high percentage of ash recovered in molten form, with consequent simplification in stack-cleaning equipment and a reduction in floor area, building volume and weight, the cyclone burner is not necessarily a universal burner in which all coals can be burned with equal facility. There are certain limitations as to ash-fusing temperature and volatile content of the coal. That is, it might be difficult to maintain the slag in fluid state with ash-fusing temperature of 2500 F and above, and a low volatile content would present difficulties in ignition and maintenance of combustion.

Based on experience with this unit at Calumet, a second unit in that station is to be provided with two 6-ft diameter vertical cyclones fired tangentially from the top, the molten slag being removed continuously from a tap hole in the bottom of each burner, and the gases passing in an essentially horizontal direction from the bottom of each burner through a water-cooled vestibule to the furnace.

Determination of Moisture Content of Coal by Means of Pulverizer Heat Balance

Citing limitations of the usual methods of sampling coal, either by hand or mechanically, and the desirability of determining the true average moisture content of coal for the operating period under consideration, **T. J. Finnegan** and **H. L. Smith,** both of the Buffalo Niagara Electric Corp., proposed means for circumventing such difficulties in a direct-fired, pulverized-coal installation. That is, pulverized coal may be sampled for the dry basis analysis and the raw coal moisture which is to be used for converting this to the "as-fired" basis may be determined by the *primary air temperature.*

In order to use the primary air temperature for determining the raw coal moisture, the rate of flow of coal and air must also be known since they, as well as the moisture, establish the primary air temperature. These data can be obtained from the control panel instruments.

The paper described in detail the manner in which this method was developed for use in the Huntley Station in Buffalo.

Application of Coal-Burning Equipment

A Panel devoted to recent trends in the design and application of industrial steam-generating units was made up of papers by eight participants, followed by a general discussion. **M. D. Engle** of the Pennsylvania Power & Light Company presided.

Survey of Post-War Units

The first paper, by **J. E. Tobey** of Fairmont Coal Bureau, reported the results of a survey of design specifications of 254 post-war steam-generating units ranging in capacity from 15,000 lb per hr up to one million pounds per hour. These comprise the majority of the larger units contracted for in 1945–46 in the sixteen states in the northeastern section of the United States and the Great Lakes region and represent a combined capacity of approximately 35 million pounds of steam per hour. Only about 20 per cent have been completed to date.

By types of firing they represent 112 pulverized-coal-fired units, 117 spreader-stoker-fired, 12 with traveling or chain grates and 13 with underfeed stokers. However, pulverized coal accounts for 78 per cent of the capacity, spreader stokers 10 per cent, traveling- and chain-grate stokers 3 per cent and underfeed stokers 3 per cent. Twenty-two units were designed for dual fuels.

Of the 112 pulverized-coal-fired units 97 are of the dry-bottom type and 15 of the wet-bottom type. They cover a wide range in coal quality, from 9780 to 14,500 Btu per lb, and the furnace heat releases in 82 per cent of the cases range from 14,500 to 24,000 Btu per cu ft, with the largest group under 20,000 Btu. In 76 per cent of these units the furnace heat available per square foot of water heating surface per hour is in the 51,000 to 100,000 Btu range; 20 per cent in the 100,000 to 150,000 Btu range and a few others ranged higher up to a maximum of 214,000 Btu.

The 117 units fired with spreader stokers represent a total capacity of 5,842,000 lb of steam per hour, a wide range in coal quality and average furnace heat release of 28,100 Btu per cu ft; the average burning rate is 38.2 lb of coal per square foot of grate area per hour.

The 12 traveling-grate and chain-grate stoker-fired units have a total steam-generating capacity of 905,000 lb per hr and burn coal ranging from 10,600 to 12,400 Btu per lb. Average ash softening temperature is 2033 F, furnace heat release 31,700 Btu per cu ft per hr, and burning rate 32.8 lb per sq ft of grate per hour.

The 13 underfeed-stoker-fired boilers represent a total steam-generating capacity of 1,021,000 lb per hr, and are designed to burn a higher grade of coal, in the range from 12,000 to 13,800 Btu per lb heating value and 2050 to 2250 F ash softening range. The burning rates range from 27.5 to 47.3 lb per sq ft per hr. Average furnace heat release is 28,800 Btu per cu ft.

Of the pulverized-coal-fired units, 38 out of 112 are in utility plants (private and municipal) with the remainder in various industrial plants. Only 15 of the 117 spreader-stoker-fired units are in utilities.

Designing Coal-Burning Equipment

Citing previous investigations to show that there is a considerable difference in the fusion characteristics of coal ash depending on whether the coal is burned in a reducing or an oxidizing atmosphere, **W. H. Rowand,** of Babcock & Wilcox Company, stated that when the average true gas temperature leaving the furnace exceeds the oxidizing initial deformation temperature of the ash, cleaning of the convection surfaces begins to become excessive. The effect of the atmosphere on the fusion characteristics helps to explain the importance of providing sufficient excess air at the burners, by minimizing air leakage, to insure efficient combustion under oxidizing conditions.

Mr. Rowand emphasized the importance of the method used to measure the gas temperature leaving the furnace. Research has shown the gas temperature as measured by a bare thermocouple to be about 150 deg F lower than that measured by a porcelain-shielded high velocity thermocouple (HVT), or about 250 deg F lower than that measured by a multiple-shield high-velocity thermocouple (MHVT) which approaches the true gas temperature. The HVT type, because of its ruggedness, is employed for test work but its readings are corrected to an MHVT basis for use in evaluation and design.

Following a discussion of the arrangement of heating surfaces to provide ample spacing and low gas velocities, as well as sufficient space for effective cleaning, the speaker stated that dry-bottom units so designed can be operated at continuous fuel inputs of 110,000 Btu per hr per sq ft of flat projected furnace cooling surface when burning coals now available in the East and Southeast. On units burning Indiana, Illinois and similar coals, the factor is generally reduced to 80,000 to 90,000.

Analyses show that the oxidizing initial deformation temperature of many coals now being used extensively in the East is only about 150 deg F higher than that in the so-called midwest coals, although the ash content is considerably lower.

A number of typical installations, together with their furnace data, were shown and the author concluded that sufficient knowledge and experience is now available to design reliable and economical dry-ash-removal steam-generating units, that will produce continuous maximum load operation with high availability and low maintenance when burning any grade of coal available today.

Fuel Economics Affecting Boiler Design

John Van Brunt, vice president of Combustion Engineering Company, summarized the economics of this problem as the design of a boiler unit to utilize to best advantage those fuels that are available in sufficient quantity at satisfactory price and which, if efficiently burned, will produce steam at the lowest possible cost, free from interruption because of any condition or character of the fuel. He cautioned against designing for burning oil alone, despite current availability and favorable price, where there is no assurance as to its continuous availability at advantageous price over the life of the unit. It is preferable to design a new unit for coal with provision for oil as an auxiliary fuel.

Surveys of available coals should include all pertinent data, such as price, proximate analysis, heating value, size distribution, coking or non-coking, initial softening and fusion temperatures of the ash and grindability. In addition, the quantities available of each kind of coal

and the possible changes in quality should be studied. For a long-range view consultations should be had with representatives of coal companies.

The decision to use stokers or pulverized coal will depend, in part, on the size of the units contemplated. In general, units of over 200,000 lb per hr output will be fired with pulverized coal. The normal field for stokers is in the capacity range up to 150,000 lb per hr, and on occasion 200,000 lb per hr.

Mr. Van Brunt expressed the opinion that those who have studied conditions over the past few years would unhesitatingly recommend that the boiler unit be designed to handle the lowest grade and cheapest fuel available at the plant; also, that the cost of a more conservatively designed unit is fully justified by the saving in fuel cost, due to ability to burn lower priced fuel, and to avoidance of forced outages because of fouled heating surfaces.

Combustion Equipment for Medium Industrial Plants

Ollison Craig, of Riley Stoker Corp., outlined the elements which must be considered in developing specifications for the purpose of obtaining satisfactory applications of fuel-burning equipment. Most important among these is cooperation between the manufacturer of such equipment and the purchaser. Responsibility for some combustion equipment installed in the past not having been as satisfactory as it should, he attributed as much to the purchaser and his engineers as to the manufacturer. Too often the purchaser is disinclined to pay more for equipment than is necessary or for equipment to serve a purpose other than that for which he can see immediate need. The result is to put manufacturers on such a competitive basis as to create an incentive to offer no more than that for which the purchaser is willing to pay.

Purchasers of combustion equipment should have their engineers specify in precise terms the things that are fundamental in obtaining equipment which will give the expected results. Such things as stoker grate area, rates of fuel burning per square foot, furnace volume, heat release per cubic foot, amount and extent of water-cooling surface in the furnace should be definitely stated and the manufacturers required to offer equipment which will meet these specifications. Such information is available to purchasers' engineers and it is possible for them to prepare definite specifications that will assure all bidders offering equipment to meet the same requirements and equipment which is not skimped in order to make the price attractive.

The American Boiler Manufacturers and Affiliated Industries Association is now making a start toward establishing standards that will provide better means for purchasers to obtain adequate offerings of equipment.

Mr. Craig then discussed the application of various types of firing equipment to medium size industrial plants which he classed as ranging from 25,000 to 150,000 lb of steam per hour. Pulverized coal firing is suitable for all bituminous coals, although it is not equally satisfactory for all such coals. However, to insure that capacity of the pulverizer will not be the cause of disappointment, purchasers should specify the worst coal conditions that can be expected.

With traveling grate stokers it is essential that the area be sufficient for the character of coal to be burned, or that the fuel-burning rate per square foot of stoker area shall not be too large. Proper application of arches and overfire jets is also important and a number of these were illustrated.

"Use of multiple-retort underfeed stokers," said Mr. Craig, "is becoming less frequent and this type of equipment has been largely replaced by pulverized coal and is still further being encroached upon by spreader stokers." The spreader type has the advantage of having the fuel burned on top of a bed of ash with the result that there is a minimum tendency for clinkering in the fuel bed. This makes this type of stoker particularly adaptable to high-ash-content, low-ash-fusion temperature coals. The stationary and dumping grate types are adaptable for the smaller installations while the combination of the spreader with the traveling grate permits installations of quite large capacities.

Combustion Equipment for Small Industrial Plants

Classifying as small plants those ranging in annual coal consumption from 2000 to 10,000 tons, **T. A. Marsh,** of Iron Fireman Mfg. Co., placed them in two groups, namely "on-track" plants which receive fuel by rail and "off track" plants which require their coal by truck from retail dealers. The larger "on-track" plants lend themselves to the same procedure of fuel survey and selection of equipment as prevails in the medium and larger industrial plants; whereas the "off-track" plants are limited to coals available through retail deliveries and at higher prices.

Since many of the smaller plants have only one steam-generating unit, reliability is of major importance. Simplicity of design and operation is indicated, hence economizers, air heaters and induced-draft fans cannot be justified. Comparatively few such plants have mechanical coal- and ash-handling equipment, although simple combustion controls are extensively used. Managements of many of these small plants believe that no economy results from burning low-priced coals. This is true only if their combustion equipment is not adapted to these coals.

Boilers have been developed in the smaller sizes to meet the requirements of this field with due consideration of draft loss, exit temperatures and use of water walls, and furnace design has kept pace with the development to permit high combustion efficiencies with low furnace maintenance. Also stoker designs embodying automatic coal transport direct from coal bin to furnace have met with acceptance because of the reduction of labor effected in plants without mechanical coal-handling equipment.

Mr. Marsh was of the opinion that present-day obsolescence and the great number of small industrial plants with definite fuel limitations and high costs present a fertile field for modernization.

Wartime Lessons in Coal Burning

The U. S. Army operates approximately three thousand power plants ranging in size from 75 to 500 hp and supplying various services. In the fiscal year 1945 they

accounted for a coal consumption of over seven million tons and during the current year will have consumed about five million tons. A wide variety of coals from practically every producing district is involved.

Discussing certain war experiences with these plants and lessons to be learned therefrom, **Carl E. Miller,** mechanical engineer of the Office of Chief of Engineers, stated that the principal difficulties had been due to lack of knowledge in many cases of available coals when selecting equipment; to designing without full regard to the plant's geographical location; and to lack of competent operating personnel—a fact not always considered when selecting equipment.

Based on wartime lessons, Mr. Miller recommended (1) that the coal industry establish regional offices to disseminate advice on fuel selection for small industrial installations; and (2) that a seal of approval by properly constituted bodies be adopted for domestic installations to assure the user coal-burning equipment that is adapted to his needs.

Future Trends

This phase of coal-burning equipment was discussed in a short paper by **F. W. Argue** of Stone & Webster Engineering Corp. which was presented by **H. J. Klotz** of that company.

The author did not anticipate radical departures from current practice and expected the present trend toward more liberal design to continue. Unit capacity should be selected carefully to suit the load duration pattern of the plant, especially in pulverized-coal firing for industrial applications. Otherwise, the furnace cooling required for full load operations might result in unstable ignition at lower ratings.

In the smaller and medium capacity range spreader stokers possess advantages heretofore considered as available only with pulverized coal. However, regardless of the type of stoker, there has been a strong trend toward more careful coordination of furnace cooling with the rate of heat release. This has made possible the use of coal that otherwise would be unsuitable, as well as longer periods of trouble-free operation at high rating.

Coal handling and ash disposal are likely to come in for greater attention.

Pulverized Fuel for the Gas Turbine

The final paper of the Panel was by **Martin Frisch,** chief engineer of Foster Wheeler Corp., who reviewed the effect of fineness on the capacity and size of pulverizing equipment with particular reference to an open-cycle pulverized-fuel-fired gas turbine.

Pulverized coal may be supplied to the turbine combustion chamber in two ways: (1) by pulverizing and storing the fuel at atmospheric pressure in the conventional pulverizing storage system and pressurizing the pulverized fuel for delivery to the burner; or (2) by pulverizing the crushed coal under pressure for direct delivery from pulverizer to burner. He described two German commercial designs of pneumatic pulverizers, the "Auger" air jet and the "Kollbohm" steam jet mill, as well as an American design, the Andrews-Willoughby, which was installed at Coaldale, Pa. in the thirties, for boiler firing.

The fineness of the product and energy consumption of these types increase with increasing load, which characteristic is quite opposite to that of mechanical pulverizers. Therefore, although they are peculiarly suited to the gas turbine and high pressure gas generation, they will have to compete with the low energy consumption of mechanical pulverizers which is about half that of the pneumatic type. On the other hand, for fine grinding such as is visualized as necessary for the gas turbine, large mechanical pulverizers would be required.

Discussion

In the discussion following presentation of this group of papers, **E. G. Bailey** observed that although coal is not actually becoming worse, it is the availability of better coal that is causing concern. The predominant tonnage of the future will be low-grade coal and very few consulting engineers are able to advise as to coal availability over a long period.

E. C. Payne stressed the desirability of fuel investigations preceding power plant design. He suggested further that it might be well for boiler manufacturers to establish regional design factors.

Theodore Maynz came to the defense of the multiple-retort stoker, citing experience of the American Viscose Co. with this type.

Replying to Mr. Frisch's comments on jet pulverizer **A. I. Yellott** said that this type of pulverizer, despite its higher power consumption, appeared to possess the flexibility required in locomotive operation, in addition to small space and weight.

Fuel Reserves

Arno C. Fieldner, chief of the Fuels and Explosives Branch, Bureau of Mines, presented a report concerning *The National Fuel Reserves and Their Relation to the Future Supply of Liquid Fuels.* Coal reserves (including lignite) are estimated by the Federal Geological Survey at 3.2 trillion net tons—about 40 to 50 per cent of world reserves (1937), while the proved reserves of petroleum (1946) are estimated at 20.8 billion barrels—about 35 per cent of world reserves. Natural gas reserves have been estimated (1945) at not less than 135 trillion cubic feet. In addition to this it is estimated that a potential reserve of 92 billion barrels of oil is obtainable from the distillation of oil shale in the United States—more than four times the present petroleum reserve. No information is available on the national reserves of fissionable materials—uranium and thorium—but, on the basis of 1600 tons of coal being equivalent to one pound of fissionable uranium products, only 800,000 tons of the latter are required to match the national reserve of 3.2 trillion tons of coal.

Solid, liquid, and gaseous fuel reserves may be summarized as amounting to the energy equivalent of 2.6 trillion tons of bituminous coal at 13,000 Btu per pound. Coal and lignite comprise 98.8 per cent of this energy reserve. Fifty-five per cent of this solid-fuel reserve consists of high-volatile bituminous coal, 23 per cent sub-bituminous coal, 19 per cent lignite, 2.5 per cent low-volatile bituminous coal, and 0.5 per cent anthracite.

No processes are operating commercially in this country for the production of fuel gases from the low-rank noncoking coals that predominate in the western states. However, such processes as were in commercial operation in Germany before and during the war may be modified for the gasification of American lignite and sub-bituminous coal, and new methods may result from American research now in progress in several organizations.

The Bureau of Mines has developed an annular metal-alloy retort which is now in pilot-plant operation at Grand Forks, N. D. A gas of high hydrogen content having a total heat value of about 310 Btu per cu ft is obtained. Other investigators are working on the gasification of these low-rank fuels in fluidized or powdered form. It is reasonable to assume that, in a few years, more efficient and more practical methods will be developed, and, with such developments, all reserves of solid fuels can be used to supplement declining reserves of natural gas and petroleum for many years—certainly not less than 1000 years and probably for 2000 years.

Factors in Smoke Abatement

Much of the "smog" generated in the heat of controversy among smoke-abatement evangelists was dispelled by a paper presented by **H. F. Hebley,** Director of Research, Pittsburgh Coal Co., which dealt with "Factors Rarely Considered in Smoke Abatement."

Many factors obscure the problem of analyzing and interpreting the data supplied by sampling stations—wind direction, atmospheric turbulence (dynamic and thermal), humidity, rainfall, seasonal and irregular variations and other factors. It is desirable, therefore, that the skilled climatologist become associated with any air pollution investigation and that the area of influence and area assigned to a deposit gage be given consideration.

The Ringelmann Chart is a convenient measure of suspended impurities, but it has its weak points. If atmospheric pollution is to be analyzed in a rational manner, a quantitative measure should be adopted with impurities expressed in milligrams per cubic meter under standard conditions. Furthermore, samples should be drawn throughout the 24 hr of the day and over an extended period because of atmospheric turbulence from day to day.

A recent development is the smoke filter in which an air pump passes samples of air through a filter and then to an absorption bottle for volumetric SO_2 determination and a dry gas meter for air volume determination. A calibrated photocell equated to the direct weighings of samples of impurities is used in conjunction with a galvanometer to measure the light passing through the stained filter. Results are reported in milligrams per cubic meter.

Atmospheric conditions aloft influence the volume of air enveloping and spread above a center of population. Large cities tend to reduce wind velocities compared to rural areas. Vertical movements as well as those of translation are dominant factors in changing the concentration of atmospheric impurities.

Air pollution is generally greater in winter due to another factor—the stability of the air. Air is stable when the colder air underlies the warmer air (inversion) and such a stratum effectively acts as a ceiling to imprison impurities released by any center of population. The best known example of recent years was the tragic event in the Meuse Valley in December 1930. Subsequent investigation indicated that the primary cause of 63 deaths was the presence of sulphuric acid formed from SO_2 released in the products of combustion from the adjacent factories of Liege.

Prolonged inversion conditions cause a state of equilibrium in the atmosphere with the amount of deposition equalling the solids discharged. The atmosphere becomes intolerable, not because of the visible particles (smoke) but because of the infinitely greater amounts of noxious gases (SO_2 and CO_2) which form the basis of air pollution associated with industrial centers. There are at least 50 times more of these gaseous particles in the atmosphere than there are solid particles.

The particles of ash and carbon emitted and held in suspension represent about 2 per cent of the total material held in polluted air. According to climatological research, dust and smoke particles are classified as inactive; they do not interact with water vapor and take little or no part in the condensation processes that lead to haze and fog. Condensation nuclei, due to their chemical nature, attract water vapor and form visible or invisible droplets. SO_2 under the influence of sunlight turns to SO_3, and with its associated water vapor forms sulphuric acid. Other substances acting as nuclei are nitrous and nitric oxides, phosphorous and common salt. The "man made" sources of nuclei are all combustion processes—whether the fuel be solid, liquid or gaseous.

The air pollution problem is not solely concerned with the visible nuisance caused by smoke and dust; the overwhelming excess of nuclei and their relationship to everchanging weather conditions represents a more complex and important aspect of the problem. The use of low-volatile coal would not overcome the fog producing condensation nuclei. What is needed is a modern research program in atmospheric pollution that would make use of the skills and experience of many professions—combustion engineers, chemists, climatologists, doctors, economists and statistical experts.

Further Graphitization Studies Reported

J. J. Kanter, of Crane Co., presented "Studies on Susceptibility of Casting Steels to Graphitization," which discussed current indications gathered from examination of six groups of carbon-molybdenum cast steels. Groups 1, 2 and 3 include steels treated with 2 lb of aluminum per ton and containing chromium ranging, respectively, from 0.01 to 0.07 per cent, 0.17 to 0.35 per cent and 0.43 to 0.70 per cent. Group 4 comprised carbon-molybdenum steel treated with $^1/_2$ lb of aluminum per ton; Group 5 treated with silicon only; and Group 6, treated with 2 lb of aluminum per ton, normalized and drawn after deposition of weld bead.

Inspection of cases in Group 1 showed that, at the end of 10,000 hr of aging at 1025 F, graphitization had advanced to a degree of unmistakable consequence. Groups 2 and 3 began to show isolated nodules of graphite after 4000 hr of aging at 1025 F, and much longer aging is necessary to determine the increase in graphitization of these chromium-bearing steels.

The curve for Group 4 practically coincides with that for Group 6. Estimate of the "half graphite" time for Groups 4 and 6 indicates that the effectiveness of either treatment increases the resistance about the same as an addition of 0.15 per cent chromium.

None of the samples in Group 5 has shown any persistent tendency to develop graphite. Unfortunately, however, these castings are not free of "pinholes." Test data suggests that another year or two of aging may dispel expectations of a readily weldable casting steel suitable for steam power plant piping to operate in 900 to 1000 F temperature range, and it becomes highly urgent that the stability of other highly alloyed casting steels be appraised.

Graphitization of Steel Piping

The most recent results of a research program instituted by the Edison Electric Institute and the Association of Edison Illuminating Companies in association with Battelle Memorial Institute were presented in a "Summary Report on Graphitization Studies on High-Temperature Welded Piping," by **A. E. White,** University of Michigan, and a "Discussion of Investigations and Company's Conclusions," by **E. L. Hopping** of the Philadelphia Electric Co.

Three distinct problems required early solutions: (1) Was graphitization present and if so to what extent had it affected the safety of the pipe? (2) If the welded piping appeared to be in safe operating condition, how long could it be expected to remain so? (3) What was the possibility of arresting or dissipating the graphite by heat treatment in the existing installations?

After two years of investigation of samples it became evident that a small sample would not disclose the uniformity or magnitude of graphitization throughout the weld. Therefore, it was decided to remove complete welds for laboratory examination. These welds, having 53,000 hr of service at Schuylkill Station and 78,000 hr at Richmond Station, were cut into quadrants which on examination, confirmed the belief that graphitization was far from uniform throughout the weld.

A welded pipe of 53,000 hr service was made in the form of a bottle and subjected to a hydrostatic pressure of 8600 psi, producing a stress in the metal of about 33,000 psi, approaching its elastic limit. No failure was detected and since the test pressure was over six times normal service pressure, it could be assumed that the weld and pipe metal would be safe for operation. Hammer blows from 35 to 150 ft-lb were also imposed on the weld while the vessel was under pressure with no indication of distress in the metal.

A section of the Schuylkill welded piping was also subjected to a tensile test, and at a stress of 41,600 psi the pipe material failed well away from the weld with a very brittle fracture which might have been due to the type and size of the specimen examined, resulting in unequal stresses. Standard test specimens of the pipe metal in the vicinity of the fracture indicated that the material had a higher tensile value and reasonable ductility instead of the brittle nature indicated by the full-sized test.

A similar test on an unwelded and unused piece of Schuylkill piping indicated good ductility and resulted in failure of the metal at a stress of 47,500 psi. A third test on unwelded Schuylkill piping which had been in service 53,000 hr disclosed good ductility and failure at 51,440 psi.

Because of the assurances given as to the safety of the pipe by practical and laboratory tests the Company decided to continue the use of this pipe. However, annual examination will be made to determine if there has been any further change in graphitization or the strength of the metal with continued service under combined temperature and stress.

From the studies made there seems to be no evidence that added graphitization has taken place after 35,000 hr. No appreciable increase in the rate of graphitization in new welds with used pipe occurred at 1100 F after 7500 hr.

The beginning of graphitization took place in increasing lengths of time as the temperature was lowered. The restoration of the properties of graphitized sections is promising if means can be found to normalize the welds at 1700 F for two hours and stress relieve them at 1300 F. The best heat treatments to use subsequent to welding are believed to be 1300 or 1375 F with a preference for the latter.

Graphitization in High Temperature Service

W. G. Conant and **W. A. Reich,** of General Electric Co., presented a paper on "Graphitization Studies of Materials for High Temperature Service in Steam Plants," which described a graphitization test using a 26 x 1 x 1-in. bar, with a weld head running full length, heated in a gradient furnace so that the material could be exposed to temperatures from 1300 F to 900 F in a single test.

Test data presented further evidence that increasing aluminum content increases the tendency of low-carbon $^1/_2$ per cent molybdenum steels to graphitize in periods of exposure up to 9606 hr at 1100 F. It was also shown that high heat-treating temperatures, in the neighborhood of 2300 F prior to welding, tend to inhibit graphitization in these same steels, and that the graphitization tendency of aluminum-killed cast low-carbon, $^1/_2$ per cent molybdenum steel is restricted by increased cooling rates during heat treatment prior to welding.

Low-carbon, 1-per cent molybdenum cast steels made without aluminum deoxidation, annealed or drawn, or normalized and drawn prior to welding, showed no graphitization at 1100 F in periods of exposure up to 9606 hr.

Two normalized and drawn low-carbon, 1-per cent molybdenum cast steels, with vanadium and without aluminum deoxidization, showed no graphitization at 1100 F after a period of exposure of 5131 hr. The addition of $^1/_2$-per cent chromium was shown to impart graphitization resistance to low or high aluminum (0.027 per cent) low-carbon, $^1/_2$-per cent molybdenum steel pipe during an exposure of 5131 hr at 1100 F.

Progress Report

S. L. Hoyt, Technical Advisor, and **A. M. Hall,** Research Engineer for Battelle Memorial Institute, presented a progress report on the research program sponsored by the Joint EEI-AEIC Subcommittee on Graphitization.

A group of selected specimens—new and old—were placed on test at 1125 F for 5000 hr. Studies of high-

aluminum deoxidized plain carbon steel and high-aluminum deoxidized carbon-molybdenum steel, by means of chemical kinetics, indicated that the test period at 1125 F was roughly equivalent to about 72,000 hr (or 8 years) at a service temperature of 925 F.

The test specimens comprised both welded joints and heat-welded bars, and included several hot and cold upset cubes, as well as a series of rectangular bars stressed elastically in cantilever to values which would not produce creep after 5000 hr at 1125 F.

The results corroborated previous observations that, other things being equal, molybdenum is a mild inhibitor of graphitization. While high aluminum deoxidized steels ($1^3/_4$ to $2^1/_4$ lb per ton) graphitize far more readily than do low-aluminum deoxidized steels ($^1/_4$ to $^1/_2$ lb per ton), completely normal silicon deoxidized steels appear to be virtually immune to graphitization.

Chromium, when added to experimental molybdenum steels in amounts of $^1/_2$ per cent or more, was found to be a very powerful inhibitor of graphite formation, effectively counteracting the bad influence of high-aluminum deoxidation. In this connection, further tests indicated that the "black spots" found in some of the experimental chromium-molybdenum steels previously tested, were not graphite. The smallness of the size and numbers in which they occurred prevented their identification, but at the same time it was held that they would not be harmful to the properties of the steel at the present stage of their development.

Limited tests indicated that vanadium and titanium may also be very effective inhibitors of graphitization.

Efforts to gather more information upon the influence of plastic deformation and of stress within the elastic limit, acting either singly or in combination with each other, produced only negative results.

Earlier work had suggested the possibility that those steels which graphitize in service contain appreciable quantities of graphite at the start (i.e., more than 0.01 per cent), while those steels which do not graphitize in service either contain no graphite initially or only very small amounts (less than 0.01 per cent). Further investigation, however, indicates that while steels which contain appreciable initial free carbon (i.e., 0.02 per cent or more) do seem to be susceptible to graphite formation, a very low initial graphite content is not a guarantee of immunity from graphitization.

Continued kinetic studies of the graphitization process confirmed the qualitative observations that post-weld stress relief often accelerates general random graphitization and that molybdenum retards graphite formation. The presence of molybdenum also appeared to alter the nature of the process to some extent, its influence evidently arising from the formation of an alloy carbide in the steel.

Influence of Post-weld Heat-Treatment on Graphitization

This was the title of a paper presented by **I. A. Rohrig** and **Arthur McCutchan** of The Detroit Edison Co. This presented the findings of a series of laboratory tests which essentially confirmed the differences previously noted in the response of high- and low-aluminum carbon-molybdenum steels to post-weld heat treatments.

Post-welding heat treatments at 1300 F appear to be more effective for high-aluminum, carbon-molybdenum pipe material than for low-aluminum material. Test results indicate that, for the latter material in the hot-rolled and drawn condition, post-welding treatments of 2 or 3 hr at 1350 F, 1400 F, or 1450 F appear to be as effective as 4 hr at 1300 F, in preventing the formation of segregated graphite. Normalizing welded joints does not entirely prevent graphitization, particularly in high-aluminum material, but indications are that normalizing after welding is highly effective for low-aluminum material.

Further laboratory heating shows that the use of austenitic chromium-nickel weld metal will prevent segregation of graphite in the weld affected area of carbon-0.50 per cent molybdenum steel used for high-temperature-steam piping.

More general graphitization may be expected to occur in used medium-carbon-steel piping after rewelding than in new material. Some graphitization occurred in all the samples of medium-carbon steel irrespective of the post-weld heat-treatment. However, stress-relieving for 1 hr at 1350 or 2 hr at 1400 F does appear to contribute to the prevention of graphitization of the segregated type in medium-carbon-steel pipe material.

In general, the test data support the recommendation that a 1400 F post-weld heat-treatment be used for preventing the formation of the segregated type of graphite at arc-welded joints.

Corrosion-Erosion of Boiler-Feed Pumps and Regulating Valves

This paper was prepared jointly by **H. A. Wagner, J. M. Decker** and **J. C. Marsh** of The Detroit Edison Company.

The troubles and failures experienced with corrosion-erosion of boiler-feed pumps and valves particularly prevalent after heavy war demands indicate a need for an investigation into ways of solving the problem

In an effort to obtain data on actual operating experiences of numerous power plants, a questionnaire was prepared by the principal boiler feed pump manufacturers and mailed to users. Although one hundred-fifty-three questionnaires were answered the results were disappointing in that many exceptions made it impossible to draw any real conclusions. Consequently, a special subcommittee of the Edison Electric Institute's Prime Movers Committee was appointed to work with the manufacturers' group for the purpose of arriving at a solution.

The Detroit Edison Company undertook tests at the Marysville Power Plant with the prime purpose of facilitating the selection of the most economical metal which can successfully withstand attack by a particular feedwater.

In these tests the feedwater was made to flow at a high velocity with great turbulence through slots in the specimens which produced a combined corrosion-erosion effect similar to that encountered in boiler-feed pumps. The specimen consisting of two circular disks, one slotted and both with ground surfaces, fitted snugly together, was held rigidly in a holder in such a way that feedwater was compelled to flow through the test slot when the desired pressure differential, usually 300 psi,

was applied across the tester. Six testers connected in parallel were operated simultaneously.

The 500-hr test period, sufficient to get results even with the most resistant material, might arbitrarily be considered equivalent to a period of 35,000 hr operation of a boiler-feed pump. Control specimens of the cast carbon-steel casing material were used in all tests to supply information regarding the uniformity of the feedwater conditions in successive tests.

The feedwater used was condensate from a 75,000-kw turbine-generator containing approximately one per cent of evaporated makeup. Total dissolved solids in the feedwater average less than 0.25 ppm. Continuous records of feedwater conditions during the test were kept.

In selecting alloy material to be tested five per cent chrome was included as it had already been ordered for pump casings at Marysville, so its characteristics were considered of primary importance.

Twelve per cent chrome and 18-8 alloy were included as representing the best alloys, notwithstanding the cost. Two to three per cent chrome steel and a low alloy of chrome-nickel-moly were included on the basis of better weldability and somewhat greater ease in casting in addition to a small saving in initial cost.

The results indicated that 18-8 followed by 12 per cent chrome were the most resistant materials. The lower chrome steels also appeared to have many times the service life of cast carbon-steel casings. The low chrome-nickel-moly steel while not as resistant as the straight chrome steel, in view of its ease in welding, holds great promise. Cast carbon-moly steel is no better than plain carbon steel while wrought carbon steels are much inferior. The four types of bronzes and monelmetal were all resistant with monel and silicon copper to a lesser extent. That no particular difficulty has been experienced in actual operation with cast phospher-bronze impeller and wearing rings was substantiated in the tests. Of particular interest was a sample of hot-rolled carbon steel coated 0.0003 in. thick with a bakelite lacquer. Although the coating had cracked off the edges it showed considerable promise.

It was found that with carbon steel, as the slot was enlarged by attack the increased water flow resulting, increased the rate of attack. This indicates the importance of a good fit in pump parts particularly those made of materials subject to attack.

As to the underlying causes of corrosion-erosion attack it would appear that temporarily high values of dissolved oxygen resulting from air leaks may have an important bearing on the problem. Results of tests at other utilities compared with these results may aid in the solution of this phase of the problem.

Discussion

George W. Kean of the Consolidated Gas, Electric Light and Power Company, Baltimore, emphasized that the rate of attack increases slightly with cross-sectional area and he believes that design and workmanship plus the use of proper material will contribute to minimizing attack. Feed pumps should have ample capacity so that continued excessive throttling will not result, thereby reducing the rate of wear.

W. F. Ryan, of Stone & Webster, cited an instance where three boiler-feed pumps in an 1100-psi station were in service eight years without repairs while two identical pumps had to be taken down after three weeks operation. He mentioned, for what it was worth, that the castings in the latter case had not been aged.

L. J. Dawson, of Ingersoll-Rand, stated that the conclusion with respect to the success of 5 per cent chrome alloy has been substantiated by field results. He also stressed the necessity for oxygen-free feedwater.

H. Hartmann, of De Laval, indicated that at first, and even now in some instances, this condition was attributed to poor fit. However, he contended that the present standard fits are satisfactory if proper materials are used. His company has had success by welding chrome alloy inserts in affected areas.

C.E. Brune, of American Gas & Electric Service Corp., told of success by welding-up affected areas, using carbon steel rods. He indicated that the repaired area has lasted better than adjacent areas.

Internal Corrosion of Furnace and Boiler Tubes

During the second session on boiler feedwater studies, three papers were presented dealing with tube corrosion.

The first paper, by **L. E. Hankison** and **M. D. Baker** of West Penn Power Company, covered the investigation of and steps taken to correct a peculiar type of "barnacle" corrosion and metal embrittlement encountered inside the furnace wall tubes of a 1350-psi boiler at Springdale Station. First notice of this unusual condition manifested itself after seven years of operation when a sudden tube failure was encountered. One of the studded furnace tubes subject to flame impingement blew out. Although this may have been a factor, barnacles were found in other areas such as the tube-end rolls in the sectional header. Many of these barnacles had broken loose on turbining and were found in the headers. Sections of several tubes examined revealed the barnacles were always found in the side of the tube adjacent to the heat input.

These barnacles which varied in size up to 2 in. by 1 in. by $^3/_4$ in. thick are predominately magnetic iron oxide interspersed with small amounts of boiler water constituents including copper. Most of them are magnetic and some have permanent-magnet properties. The barnacle has a pyramid or conical top which started as a small seed and grew in a series of cycles due to change in rating or heat input by feeding on the tube metal.

Examination of several sections with barnacle growth revealed that in all cases except under the smaller barnacles hydrogen attack or embrittlement had developed. Examination of the fractured metal at a blowout showed that fully 90 per cent of the remaining metal was embrittled and only $^1/_{32}$ in. of ductile metal was all that held the boiler pressure. It is evident that the embrittled metal has very low ductility, impaired tensile strength and lowered heat conductivity.

Because of the apprehension regarding safety of continued operation of the boilers a section of tube that was thinned externally and had heavy barnacle corrosion inside was capped at each end and hydrostatically tested. The tube failed at 7400 psi. Examination following this test revealed considerable embrittlement.

Prior to discovery of the barnacle formations the boilers had been acid cleaned. It was believed the acid cleaning removed a protective coating of iron sulphite-phosphate compound. The boilers were opened frequently following this cleaning thus exposing the clean unprotected metal surface to atmospheric corrosion and probable development of the barnacle "seed."

Also during the period between acid cleaning and the first failure the dissolved oxygen was as high as 0.30 ppm, sulphite was not being used for boiler water conditioning; and the percentage of copper in the boiler deposits was high.

Corrective steps included reduction of the dissolved oxygen content of the feedwater to 0.02 ppm or below, maintenance of sulphite at 3 to 10 ppm in the boiler water and reduction of the ammonia content of the feedwater which lowered the amount of copper and its compounds in the boiler sludge. As a result the barnacle development and metal embrittlement has been stopped. Continuous operation for $1^1/_2$ years with the deteriorated metal has produced no appreciable trouble.

It was concluded that the barnacle growth and embrittlement stopped when sulphite feeding was resumed. Also attributable was the reduction of oxygen in the feedwater.

Experiences at West End Station

The second paper, by **E. H. Mitsch** and **B. J. Yeager**, of the Cincinnati Gas & Electric Co., dealt with another form of corrosion encountered in 1450-psi boilers at West End Station. After a period of three years of operation without difficulty there developed a pit-type of corrosion in certain tubes. Failure of a furnace tube in April 1940 led to the discovery of similar corrosion in other parts of the boiler. A year later the first failure by corrosion at the rolled joints of tubes occurred on another boiler.

Prior to these failures the boilers had been operated at reasonably steady load conditions. Inspection during this period did not reveal any unusual corrosion conditions. From January 1940 to October 1941 the boilers were subjected to rapidly swinging loads which caused large pressure changes.

It was found that oxygen had entered the system at several locations. Sodium-sulphite feed to the boilers was started at this time. Several months prior to the first tube failure the alkalinity of the water in that boiler was reduced to half the normal figure while it was kept normal in the other two boilers which had no pitting.

The first evidence of corrosion of the tube-rolled joints was failure during hydrostatic test of one of the other boilers. The corrosion extended several inches beyond the rolled joints and failure was by cracking of the embrittled metal in this area. A loose deposit was formed on several rolled joints but only on those that were being attacked by corrosion. In these cases the protecting blocks were missing thus allowing more heat nearer the tube joint.

During the past five years the boiler load has been steady. Since April 1942 when the alkalinity of the water was increased there has been no further rolled-joint corrosion or tube pitting. Sodium sulphite feed was used to scavenge oxygen since April 1940.

Brittle Type of Tube Attack

The third paper was by **Prof. F. G. Straub** of the University of Illinois Engineering Experiment Station who described several instances of boiler-tube failure of the non-brittle and the brittle type. Although several theories on embrittlement have been advanced the author concluded that this type of failure is caused principally by dissolved oxygen in the absence of an oxygen scavenger. He described his experiences with the brittle type of tube attack at the Akron plant of the Firestone Tire & Rubber Company and at Fisk Station of the Commonwealth Edison Company.

Although this boiler was put in operation in 1934 serious corrosion of furnace-wall tubes did not occur until 1944. Then during turbining of the tubes heavy magnetic-oxide scale was found. Continued operation with numerous changes in feedwater treatment did not check a siege of tube failures.

The author was called in as a consultant on the case. It was then decided to acid-clean the boiler to remove the silica scale in the generating tubes and the possibility of magnetic oxide remaining in the undiscovered pits in water wall tubes. A large amount of copper was loosened in this cleaning. Operation then continued with modification of feedwater treatment and special routine to be followed after each outage. Subsequent examinations showed no indications of the rapid and severe internal corrosion previously noted.

The second instance of brittle-tube failure discussed was that experienced at the Fisk Station, Chicago. After $1^1/_2$ yr of operation the boilers were acid cleaned. Two years later a number of furnace tubes failed. Examination of the failed portions revealed magnetic oxide with the tube metal reduced in thickness, decarbonized and containing intercrystalline cracks. Micro-examination of the organic matter at the point of failure revealed asbestos fibers. The source of these was the asphalt-asbestos cement with which the interior of the water reservoirs were painted. As a result the silica content of the boiler, water had run as high as 40 ppm.

Operation is continuing without serious attack following remedial measures including sodium sulphite treatment of the feedwater.

The last case discussed by Professor Straub was that of the corrosion experienced at Mystic Station of the Boston Edison Company. Here the corrosion occurred as a result of concentration of the boiler water under the iron-oxide sludge on the tube surface. Magnetite carried into the boiler appeared to adhere to the steaming area of the tubes thus preventing the boiler water from sweeping the metal surface and allowed the boiler water salts to concentrate between the metal surface and the adhering magnetite. It was decided in this case to check the corrosion by going to coordinated phosphate control in which the salts left behind by evaporation do not contain free sodium hydroxide. Subsequent inspection failed to show signs of continued corrosion.

Discussion

R. C. Corey, of Combustion Engineering Company spoke of the striking similarity between the Firestone and Springdale cases and mentioned the finding of solid pieces of magnetite in the headers at Firestone. Also, both units operated between 7 and 10 years before any

troubles developed. He stated that Firestone has operated 18 months since acid cleaning without trouble, as indicated by frequent examination of furnace-wall tubes over this period since changing water treatment early in 1945. The obtaining of case histories and field data are contributing markedly to the ultimate determination of the cause of these troubles.

J. B. Romer of Babcock & Wilcox Company defended shop welds, saying that although some failures occurred near them, many were in other locations indicating that the welds were not generally a contributing cause.

G. A. Orrok, of the Boston Edison Company, advanced the theory that the point in the tubes where evaporation began with the formation of small bubbles may be where trouble initiates.

Effect of Repeated Acid Cleaning on Boiler Metal

H. C. Farmer, chief chemist of the Philadelphia Electric Company, described an investigation made by that company to reveal something more definite about inhibited acid attack on boiler metal under variable conditions.

To ascertain the effect of varying the temperature and concentration of the acid and the time of contact, samples of stressed boiler tubes (actually the flared ends) from Deepwater Station and of a new tube for Schuylkill Station were subjected to several hundred tests. It was definitely proved that a corrosion attack will be more severe on stressed metal than on normal or stress-relieved metal. The flared tube ends, which are rolled into the seats cold, are more vulnerable to acid attack, regardless of the presence of an inhibitor.

When using 10 per cent inhibited acid the losses are at least twice as great as when 5 per cent inhibited acid is employed in the temperature range of 140 to 175 F on both stressed and stress-relieved specimens. In order to minimize metal attack when acid-cleaning boilers, the solvent should not exceed 5 per cent acid strength, should be approximately 140 F and the contact time should not exceed six hours. Also, to avoid hot spots it was recommended that the boiler first be cooled down, then preheated to 160 F and allowed to cool uniformly to 140 F.

Following establishment of this criteria, studies were next directed to obtain some practical information on the effect of repeated acid cleaning. Life tests were devised, simulating repeated actual boiler washing conditions. These tests consisted of six-hour immersion in 5 per cent inhibited acid at 140 F. The specimens were then boiled in a soda ash solution and immersed in boiling water for 16 hours. Twenty-five such cycles constituted a life test. Results indicated that the corrosion loss proceeded at a fairly uniform rate for all stressed specimens, these losses being about three times greater than experienced with the stress-relieved specimens.

To be sure that results could be reproduced, five life tests were run on representative samples of the different specimens. All the results were confirmed. During this phase it was proved that when the stressed portion was removed (only 0.010 in. was machined off) the corrosion rate was the same as that of unstressed metal. It would then appear that after the acid had attacked and removed the highly stressed area of the Deepwater tube end, very little attack occurred. Penetration of attack will therefore be governed by the depth to which the metal is stressed.

The pressure and the amount of ferric iron in the boiler deposits may be a factor in metal attack since the inhibitor does not protect the metal from attack on steel by ferric chloride.

The total loss of metal after twenty-five treatments of 6 hr each with 5 per cent acid at 140 F amounted to 0.10 lb per sq ft or a loss in metal thickness of approximately 0.0025 in. However, test data show that at a temperature of 175 F and 10 per cent acid for 24 hr continuous contact time, the approximate loss was 0.20 lb per sq ft for a single treatment.

Discussion

M. H. Kuhner, of Riley Stoker Company, in discussing Mr. Farmer's paper pointed out that the flared tube ends, which are vulnerable to acid attack, really serve no useful purpose. Several tests made by his company indicate that the flared tube actually has less holding power than one not flared. Furthermore, without flaring there is no need for the tube to project inside the drum at all.

Steam Turbines for High-Powered Combatant Ships

In this paper, **G. B. Warren,** of the General Electric Company, discussed factors leading up to the selection of turbine design for combat ships constructed after the expansion program started just prior to the war. He pointed out that, although at the turn of the last century marine power plant design had led land installations, with the birth of the electrical central station industry, the trend swung the other way and by 1930 land or stationary power plants far surpassed current marine practice as to efficiency, size and reliability. In order to modernize marine design a small group in the Bureau of Engineering of the Navy and in the shipbuilding industry enlisted the services of central station machinery builders in undertaking design and construction of boilers, turbines and auxiliaries. The result was the development of new high-speed, light weight and sturdy propulsion equipment for a group of high-powered destroyers, later called the Mahan class.

The power plants for these ships were to be of 42,000 hp at 385 psi and 620 F at the turbine throttle and with modifications in superheaters to develop 52,000 hp at 400 rpm, 375 psi and 825 F.

A radically new type of "locked train" main propulsion reduction gear was adopted which permitted building a double-reduction gear of great rigidity and light weight and much higher turbine speeds. Further advantage of the higher speeds, 5000 to 6000 rpm, was reduction of the diameter and also the between-bearing spans of the turbines. Shorter spans and resulting smaller shaft diameter resulted in rugged machinery which would greatly minimize leakage difficulties when subject to the rapidly changing load requirements of naval propulsion turbines.

Another requirement which entered into development of the destroyer turbines was ability to cruise long distances at 12 to 15 knots with only 2 to 4 per cent of normal full-power output. A cruising turbine arrangement with this turbine always in gear which would operate at 10,500 rpm at full power of the main turbines was selected. Above 22 knots the cruising turbine exhausted into a main high-pressure-low-pressure crossover pipe and steam flow corresponding to this speed passed through it for cooling.

Another innovation was suspending the condenser and hot-well pump below the turbine and employment of special construction features to compensate for the distortion experienced in destroyer hulls.

A rigid service test requiring the running at full power astern for one hour resulted in having to redesign the turbine to reduce overheating.

In planning the Somers class of destroyer leaders in 1935 pressures were raised to 600 psi. Later when the 1938 capital shipbuilding program was started, it was also decided to go to 600 psi and 825 F and to eliminate cruising turbines which of course simplified the control of the high-pressure turbines. These turbines were rated at 53,000 hp per propeller shaft.

A considerable amount of standardization was obtained as four sizes of turbines at ratings of 25,000, 30,000, 37,500 and 53,000 hp powered practically all the combatant ships and many parts were interchangeable.

Although factors of safety may have seemed unduly high the wisdom of conservative design has been proved by the fact that bucket failures have been insignificant on some 30,000,000 hp of turbines built for the Navy during this period. In spite of the radical innovations of these turbine designs and lack of battle experience, comparatively few difficulties were encountered. The basic designs were later standardized for all classes of ships.

To keep pace with trends in power plant design there was installed in 1939 in World War I destroyer *Dahlgren*, an experimental plant to operate at 1200 psi and 900 F. Several years' operation indicate that these conditions are practicable for Navy service.

Flue-Gas Recirculation

Application of flue-gas recirculation to temper the gases ahead of the 1400 F separately fired superheater at the Neches Butane Products Plant was described in a paper by **W. H. Rowand** and **E. Durham,** both of Babcock & Wilcox Company.

The authors pointed out that temperature of the gases from direct combustion with normal excess air is ordinarily too high for direct application to heat-exchangers in which the heat-absorbing medium is steam or gas, unless tremendously high mass flows with their costly pressure losses or expensive alloys, or both, are resorted to. Gas recirculation reduces the temperature of the gases entering the heat-exchanger to the point where sensible design conditions may be safely projected into actual operation, carried out with reasonable care and under simple control limitations. While the use of air to temper the gases would accomplish the purpose of maintaining the metal temperature at safe levels, it would be inefficient; whereas use of a portion of the relatively cool gases leaving the heat exchanger does not appreciably affect the efficiency and requires less fan power.

After describing the Neches installation, the paper reviewed a number of potential applications of flue gas recirculation in various industrial processes and suggested further that in the power field, where space conditions prevent use of sufficient radiant heat-absorbing surface to cool the gases below the fusion point of the ash, flue-gas recirculation may be employed to cool the gases and thus prevent slagging trouble.

*Furnace Temperature Control for Large Steam-Generating Units**

Following a discussion of bypass damper control and the use of desuperheating for regulating steam temperature, the author reviews the effect of furnace gas outlet temperature on superheat and presents data from tests with tilting burners in tangential firing. By this means furnace outlet temperatures may be selectively controlled over a range of 200 deg from low load to maximum load and when supplemented with bypass dampers it is possible to maintain the superheat within less than 5 deg from normal over very wide load ranges.

By OTTO de LORENZI

Director of Education,
Combustion Engineering Company, Inc.

Ability to adjust the furnace outlet temperature of large steam-generating units enables the operator to maintain a uniform superheated steam temperature over a wider range in capacity than is possible with any other presently available means.

The amount of superheater surface, and its location in a given steam-generating unit, is usually fixed by the steam temperature required at some specific capacity and by the fuel used. The performance of this superheater at capacity points other than that for which it is designed will depend upon the temperature and mass-flow of the gas sweeping over its surface, the temperature of the feedwater, the cleanliness of the furnace heat-absorbing surfaces and the output at which the unit is operated. Typical performance characteristics for a convection-type superheater as used with large public-utility type of steam-generating units is shown in Fig. 1. The contour of the temperature-capacity curve is fixed and it can only be shifted bodily upward or downward by changing either the amount of gas which flows over the superheater or the entering gas temperature. The change in gas flow may be secured through some form of bypass arrangement. The temperature change can be accomplished by decreasing or increasing the amount of heat-absorbing surface which is used to screen the superheater.

The Bypass Damper

Many present-day units are equipped with automatically controlled bypass dampers to provide for constant temperature at the superheater outlet, over a relatively wide range in capacity. Typical performance characteristics of a superheater with controlled gas-bypass arrangement is shown in Fig. 2. The amount of steam temperature regulation which may be obtained in this manner ranges between 60 and 80 deg F through bypassing a proportion of the gas. The superheater surface is therefore selected and arranged so that at maximum capacity, with bypass closed, the steam temperature will be 60 or 80 deg F higher than desired. Normal steam temperature is then obtained when the bypass is fully open. With the bypass fully closed it is

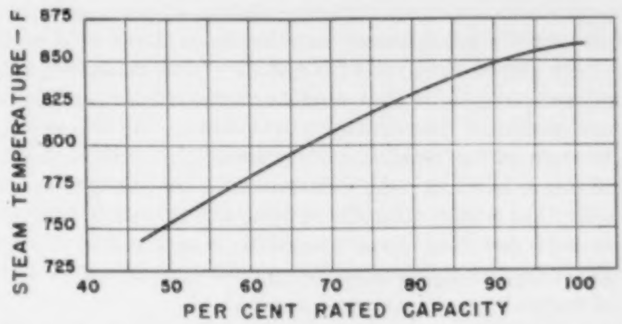


Fig. 1—Performance characteristics of a typical convection superheater

possible to obtain normal steam temperature at some lower load point which is, in turn, fixed by the superheater characteristic curve.

While bypass-damper control provides an acceptable means for steam temperature regulation, there is apt to be hunting in positioning the damper when load changes are abrupt, frequent and of considerable magnitude. There is naturally some lag in response to temperature change, with a resulting variation in range that may be as much as ±10 deg F. This variation is characteristic where the regulation of steam temperature depends solely on control of gas flow through bypass damper operation.

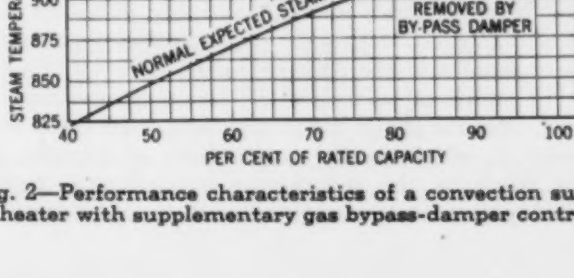


Fig. 2—Performance characteristics of a convection superheater with supplementary gas bypass-damper control

* From a paper presented at the Annual Meeting of the American Society of Mechanical Engineers, December 2 to 6, 1946.

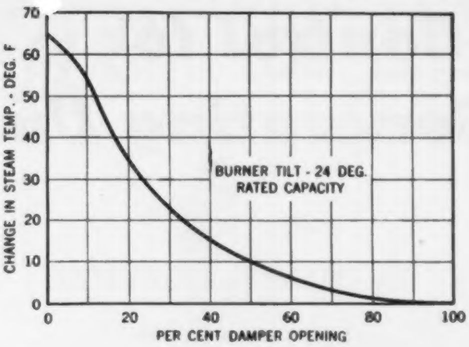


Fig. 3—Curve showing steam temperature change with respect to bypass-damper opening

The reason for the foregoing are the relatively rapid increases in flow during the early damper opening periods and then, as the fully open position is approached, the relative flow increase falls off. This operating characteristic is illustrated by the curve in Fig. 3. These data were taken from an actual test during which the capacity of a large steam-generating unit was held constant and the effect of variable bypass-damper opening on steam temperature recorded. It will be noted that there is an increase of 15 deg F in steam temperature for a change in damper opening from 100 per cent to 40 per cent open. However, the temperature increase from 40 per cent open to fully closed damper is 50 deg F. It is, therefore, immediately apparent that sensitive responses, resulting in more uniform temperature, are obtainable where the operation of the regulator is confined to the early stages of damper opening. In other words, any changes in capacity that would normally require the bypass to operate above 50 per cent open should be compensated for by other adjustments so as to keep within the sensitive control range.

Desuperheaters

An alternate or sometimes supplementary arrangement to the bypass damper, which has been provided for in a number of installations, is some form of desuperheater, either of the direct-contact or the non-contact type. These desuperheaters are used to effect a reduction in temperature of the superheated steam. They are preferably located between sections of the superheater, especially where the final steam temperature is above 850 F. With these interstage installations, the steam is first passed through a primary superheater, where it is raised to some intermediate temperature which may be only slightly under that finally desired. It is then passed through the desuperheater in which its temperature reduction is controlled so that after continuing through the final stage of the superheater, the required final temperature is maintained at the outlet. Desuperheaters do not necessarily function to extend the range over which constant steam temperature is obtainable except in those cases where the superheater is of considerably increased size. This size increase will shift the temperature-capacity curve upward and the desuperheating effect obtainable must be sufficient to reduce the steam temperature to normal, over the range where it is high. The minimum capacity at which normal temperature is obtained remains fixed by the superheater characteristic curve. Typical performance curves of units having desuperheaters located inter-stage and at superheater outlet are shown in Fig. 4.

Use of desuperheaters has not been particularly popular with steam plant operators even though sound designs are available. Perhaps the reasons are: With the direct-contact type water is injected into the steam, to effect temperature reduction, and there is the ever-present possibility of moisture carryover into the final superheating stage; and if the sprays are improperly adjusted or controlled the non-contact types are large heat-exchanger types of vessels suitable for high-pressure and high-temperature operation, and therefore bulky, heavy, costly and subject to service interruption common with equipment of this type.

Both bypass damper and desuperheater methods for steam temperature control are of the indirect type. The first secures its results through shunting part of the flue gas around the superheater surface so as to vary heat input to the steam. The second depends for its effectiveness on absorbing some of the heat contained in the superheated steam to obtain the final required temperature conditions. With both of these methods the fuel burners remain in a fixed position and, for any given capacity, the gas temperature and its volume at furnace outlet can only be changed by increasing or decreasing excess air. This inflexibility of furnace conditions makes it necessary for those units which must operate with constant steam temperature, over a wide capacity range, to select a relatively high heat-liberation rate at the lower output and then accept perhaps unfavorable conditions at the maximum output. Or, if the heat-liberation rate is selected to produce favorable furnace conditions at

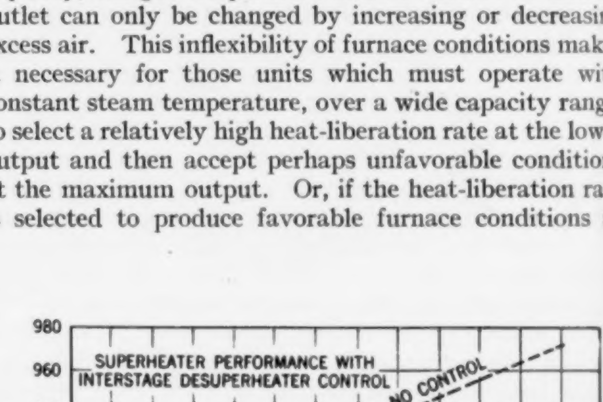


Fig. 4—Curve showing performance of superheater with desuperheater control installed interstage and at superheater outlet

maximum output, then the range over which constant steam temperature can be obtained is materially reduced.

Effect of Furnace Wall Cleanliness

A factor which has considerable bearing on superheater performance, regardless of the method used for temperature control, is furnace-wall effectiveness in absorbing a large part of the heat liberated in the furnace cavity. This heat is transmitted into the boiler water through a combination of radiant, convection and conduction transfer. The greater amount of heat, by far, is transmitted by radiation from the incandescent mass of turbulent burning fuel to the wall surface, and then by conduction into the boiler water. The amount transmitted by convection will depend on the method employed for burning the fuel and the extent to which the flame mass sweeps over the furnace-wall surface. The surface condition of the furnace-wall tubes also have considerable bearing on the amount of heat that can be absorbed and this directly affects the furnace temperature conditions that are obtained. A newly installed bare-tube wall will absorb large quantities of the liberated heat with the result that furnace temperature, and likewise steam temperature, may be considerably lower than predicted. After the furnace has had an opportunity to become seasoned because of continued operation, its temperature will rise and also cause the steam temperature to increase. If basic data and calculations are not in error, the predicted performance will then be obtained. Of course, if performance of the unit is based on fully purged wall surface, then, after the seasoning period, steam temperature may be too high at top load for safe turbine operation. If the wall becomes too severely coated with slag and dust deposits due to long continued periods of operation at maximum capacity, or to a coal with lower ash-fusion temperature than originally anticipated, temperature conditions approaching those of an all-refractory furnace lining may be obtained. This condition will then result in further acceleration of the slag deposits and may eventually force a shutdown for thorough de-slagging and cleaning. Of course, the use of soot-blowers and hand-lances will extend the time between outages for cleaning. On the other hand, if the load is a swinging one or has extended peaks and valleys, a self-cleaning action will result from the changes in rate of heat liberation. The wall accumulations, as well as those on the convection surfaces, will drop off so that a more effective condition for heat-absorption will exist. However, this may also result in a lower steam temperature during the early stages of the load pick-up and continue until the proper degree of furnace-wall coating has been re-established.

The foregoing conditions are illustrated in Fig. 5 in which station-operating data, for a large public-utility installation, have been plotted. These data are presented in this manner because the actual station charts were not available for direct reproduction. The unit under discussion is designed for a continuous capacity of 425,000 lb of steam per hour at 1325 psi and 935 F. Bypass-damper control is provided to maintain constant steam temperature down to the three-quarters load point, or 320,000 lb of steam per hour. At one-half load the predicted steam temperature is 860 F. A fully water-cooled continuous-discharge slag-tap furnace, using bare-tube construction, is supplied with pulverized coal through tangential-type burners located in each corner. At maximum capacity the furnace liberation rate is approximately 23,000 Btu per cu ft and at three-quarters load 17,000 Btu per cu ft per hour.

It will be noted that the load carried by this unit between 11 p.m. and 7 a.m. is approximately 240,000 lb of steam per hour. The steam temperature during the same period gradually falls off from a high of 840 F to a low of 750 F at 6:45 a.m., even though the bypass damper remains fully closed. To operate under this low-load condition only a portion of the pulverizing equipment, with its corresponding burners, is used. Because of the decreased fuel-burning rate there is a reduction in furnace temperature which, in turn, causes the furnace walls to gradually shed a portion of the slag and dust accumulated on them, thus making them capable of increased heat absorption. The increase in heat absorption reflects itself in a further lowering of the furnace temperature as well as steam temperature. This action then accounts for the reduction of 90 deg F in steam temperature, at constant load, during this period.

How the reverse of wall shedding affects superheater performance is shown by the load and corresponding

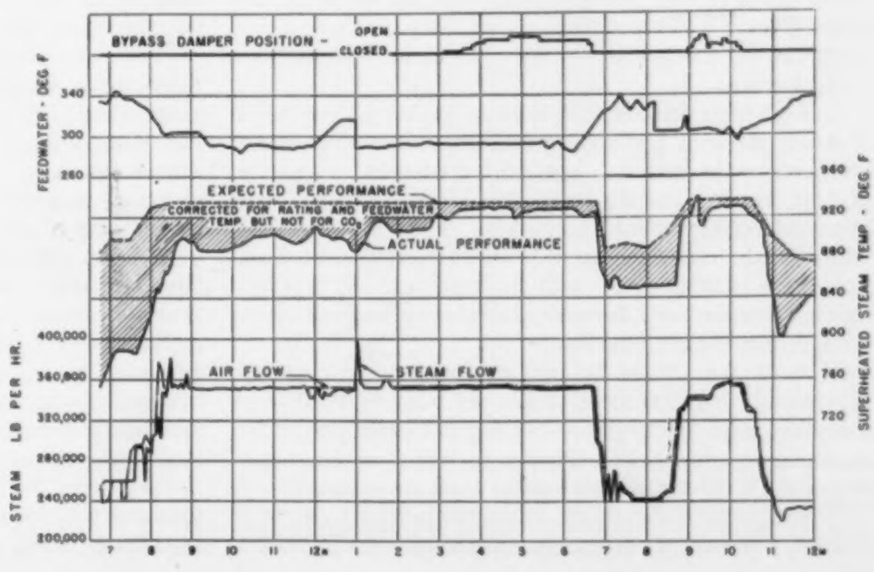


Fig. 5—Actual superheater performance obtained on a large public utility installation in which fixed fuel nozzles and bypass-damper control are used

steam temperature line between 7 a.m. and 10:30 p.m. As the load begins to increase between 7 a.m. and 8:30 a.m. there is a corresponding increase in steam temperature resulting from the larger amount of fuel burned. Between 8:30 a.m. and 6:45 p.m. the load is practically stabilized at approximately 350,000 lb of steam per hour. During this same period the steam temperature gradually increases from 900 F and, at 3:30 p.m., reaches 930 F at which time the bypass damper becomes operative to maintain a relatively constant temperature. This increase in steam temperature, over the high-load operating period, is due to a gradual accumulation of slag and dust deposits, on furnace wall surfaces, which reduce the rate of heat absorption and thereby cause a rise in furnace temperature. Then at the point

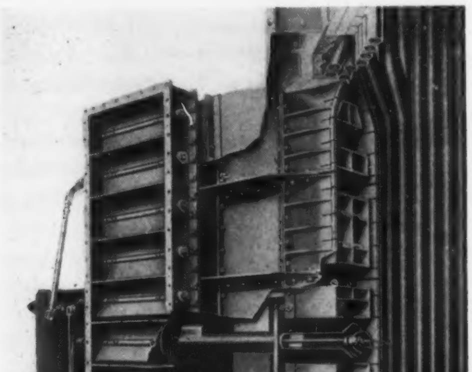


Fig. 6—C-E Type T Burners for tangential firing. Operating mechanisms for secondary dampers and adjustable fuel nozzles are shown

where furnace temperature and flue-gas quantity become greater than required to produce normal steam temperature, the bypass damper begins to function as a control means.

At 6:45 p.m. there is a sharp drop in load to 240,000 lb of steam per hour and a simultaneous reduction in steam temperature to 850 F. The unit continues to operate at this lower capacity and steam temperature, with bypass damper closed, until 8:45 p.m. Because this valley in the capacity curve is of relatively short duration there is little or no wall-shedding and, as a result, furnace temperature, furnace heat absorption and steam temperature remain constant.

At 8:45 p.m. there is another load increase to approximately 350,000 lb of steam per hour and this rate continues until 10:15 p.m. During this same period the steam temperature rises sharply to 930 F and is maintained at this level through bypass damper operation.

Directly above the actual steam temperature record is plotted a curve of expected superheater performance, based on the actual feedwater temperature. The shaded area between these two steam temperature curves represents divergence in performance which frequently results in units where excessive furnace shedding occurs.

Effect of Feedwater Temperature

Variation in feedwater temperature is another factor which influences superheater performance because it affects the amount of fuel that must be burned to produce a given quantity of steam at a specific pressure and temperature. Thus variation in feed temperature means variation in gas flow over the superheater surface with a corresponding increase or decrease in steam temperature. Some degree of performance divergence, discussed in the previous paragraph, may be attributed to feedwater temperature. The actual recorded feedwater temperatures, for the unit cited in the foregoing discussion, are plotted above the superheater performance curves in Fig. 5. Periods of high feedwater temperature occur during low load and therefore contribute to the drop in steam temperature because of the resultant reduction in heat input requirements.

Control of Furnace Exit Gas Temperature

The demand for constant steam temperature at the superheater outlet, over a wide range in capacity, presents a serious design problem. It is one in which temperature of the products of combustion leaving the furnace must be sufficiently high to effect the necessary heat transfer, yet avoid deposition of slag on the heat-absorbing surfaces. If the gas temperature is high enough at partial load to obtain full superheat, then at full load it may be too high to avoid slagging. Furthermore, wide fluctuations and divergence in steam temperature are almost wholly due to changes in gas temperature resulting from variations in furnace operating conditions. It becomes apparent, therefore, that the logical approach to overcome these difficulties must provide for maintaining favorable operating conditions in a direct and positive manner. With the design employed it must be possible to quickly adjust the temperature of gas flowing over the superheater to secure desired steam temperature. It must also be possible to selectively make a relative change in furnace volume and areas of heat-absorbing surface. The foregoing requirements are met through positioning the zone of turbulent combustion in the furnace cavity and thereby apparently modify the heat-liberation rate, and correspondingly change effectiveness of the furnace heat-absorbing surface, to produce a temperature at furnace outlet which results in the desired degree of superheat. A bypass damper is used as a means for final incremental adjustment of steam temperature.

The foregoing can be best accomplished in tangentially fired furnaces because the radiation and convection transfer, due to sweeping action of the envelope over the wall surface, is greater than with any other method of firing. The burners, Fig. 6, are installed in the four corners of the furnace and each is provided with fuel nozzles that may be elevated or depressed as much as 30 deg from the horizontal. The adjustment of burner nozzles may be by either electric motor or hydraulic cylinder and the control button is located on the boiler-operating panel. The regulation of furnace tempera-

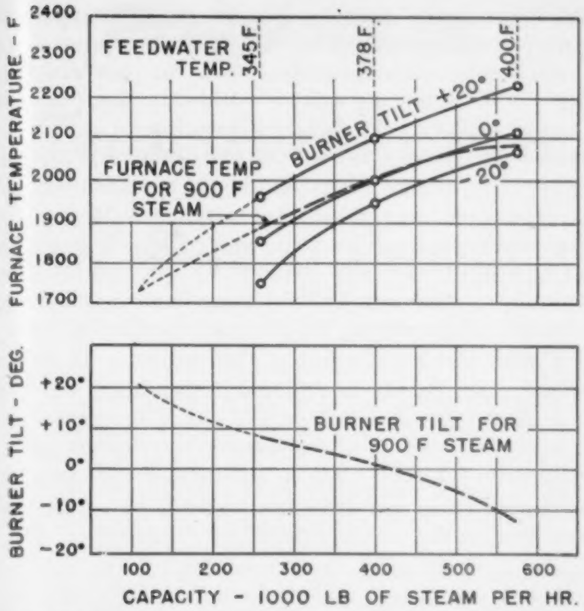


Fig. 7—Effect of burner tilt on furnace outlet temperature and steam temperature obtained with the unit shown in Fig. 8

ture is then accomplished through change in burner-nozzle elevation. Thus, by directing the incandescent turbulent mass of burning fuel toward the upper zones of the furnace, the resulting outlet temperature will be higher during light load, or when walls are clean, than would be the case with fixed burners which constantly use the entire provided furnace volume. For heavy loads, or when walls are coated with dust, the entire furnace volume can be used to maintain the desired outlet temperature by tilting the burner nozzles downward. Now, by adjusting the burner nozzle to the proper angularity for any given and reasonable varying load condition, a bypass damper can be confined to its most effective operating range. Thus the combination of adjustable burner nozzles for control of furnace outlet temperature with a bypass damper for final incremental regulation of steam temperature, through variation in gas flow over the superheater, provides a positive combination for maintaining the desired degree of superheat, with less variation from normal, over a far wider operating range than where a bypass damper and fixed burners are used.

The effect of burner adjustment on furnace outlet temperature and steam temperature is graphically illustrated in Fig. 7. These data were obtained from the large public-utility type of C-E steam-generating unit, illustrated in Fig. 8. The unit providing these data has a maximum continuous capacity of 525,000 lb of steam per hour at 875 psi and 900 F. It is equipped with a completely water-cooled, hopper-bottom type, tangentially fired furnace. The furnace heat-liberation rate at maximum capacity is 19,600 Btu per cu ft. The burner nozzles are adjustable by push-button control, installed on the boiler-operating panel, through a maximum of ±24 deg from the horizontal. The fuel is an eastern bituminous coal with an ash-fusion temperature of 2400–2500 F.

To obtain the data used in preparing Fig. 7, the unit was operated at evaporative rates of 260,000, 400,000 and 575,000 lb of steam per hour. At the 260,000-lb per hr point the bypass damper was set at 25 per cent open so as to hold steam temperature within safe limits for turbine operation. A series of furnace temperature reading along with other essential data were then recorded for burner tilts of −20, 0 and +20 deg. Similar data were likewise recorded for the 400,000 and the 575,000-lb per hour load points. All of these data were then used to prepare the three curves of Fig. 7 to show change in furnace outlet temperature with capacity for the three burner nozzle positions. Superimposed on these curves is one which shows the furnace outlet temperature required to produce the predicted constant steam temperature with bypass damper fully closed. It will be noted that this curve falls within the range of temperature obtainable through burner nozzle tilting, from a maximum capacity of above 575,000 lb per hour down to well below a capacity of 200,000 lb of steam per hour. Of particular interest is that, at maximum capacity recorded, the furnace temperature required to produce steam at 900 F is below 2100 F. This temperature is well below the ash-fusion temperature of the coal burned and thus there are no furnace-wall or convection-surface deposits which would require other than perfunctory operation of soot-blowing equipment. Under these operating conditions the bypass damper is used for final incremental control of the steam temperature and not as a compensating means which shunts a relatively large quantity of gas around the superheater to obtain some degree of temperature control.

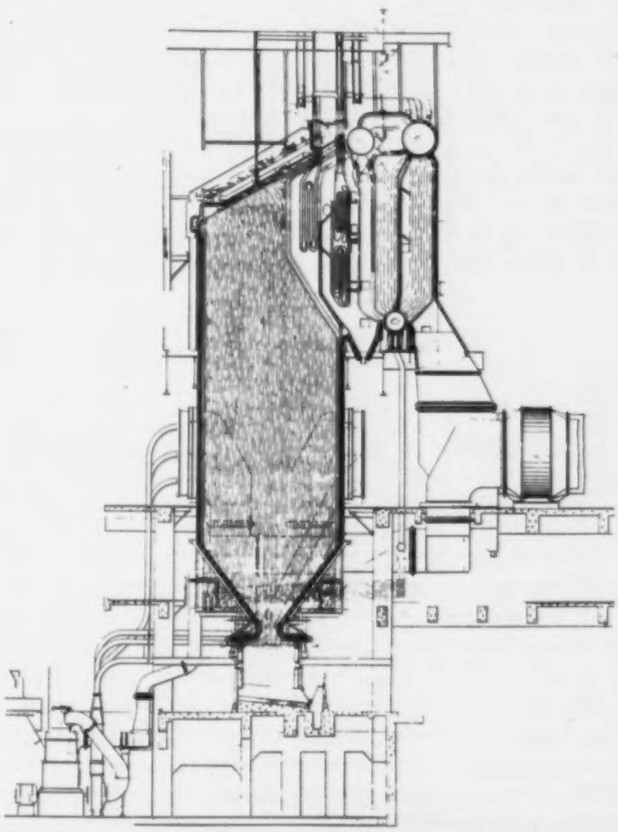


Fig. 8—C-E steam-generating unit installed for a large public utility station. Capacity 525,000 lb of steam per hour at 875 psi and 900 F. Both bypass-damper control and adjustable fuel nozzles are used to obtain temperature control over a wide range in capacity

Additional data on the relation between burner tilt and furnace temperature were obtained in another C-E steam-generating unit having a maximum capacity of 600,000 lb of steam per hour at 875 psi and a steam temperature of 900 F. The fuel is either eastern bituminous coal or natural gas. The burners supplied with this installation may be tilted through the range of −25 deg to +25 deg, from the horizontal. Data were recorded for operation with pulverized-coal and also natural-gas firing. In each instance the actual readings obtained were corrected to a fixed percentage of excess air so that direct comparisons, for the several load points, may be made without difficulty. These percentages of excess air are averages which represent normal daily operation. For pulverized coal the corrected results are based on 20 per cent excess air in the gas leaving the furnace. For natural gas they are based on 12 per cent excess air.

Data were recorded with coal firing at four different load points. For the 590,000 and 490,000 lb of steam per hour rate, three burner nozzles were used in each corner of the furnace. At 350,000 and 200,000 lb per hour the two upper burner nozzles were used and an extra run was made at 350,000 lb per hour with the two lower nozzles in service. All of these data are plotted in Fig. 9. The group of furnace temperature curves resulting from natural-gas firing have a somewhat less slope than those obtained with pulverized-coal firing. This difference is directly attributable to smaller amount of heat-absorption in the furnace walls because of decreased luminosity and corresponding reduction in radiation transfer from the burning fuel. This is again checked by the lower group of curves which show steam temperature, with bypass closed, for the several conditions and again, with natural gas, a smaller slope because there is greater transfer of heat to the superheater by convection which tends to flatten the curve.

As is the case with the previously cited installation, the spread in the furnace outlet temperature resulting from burner tilt is sufficient to provide for constant steam temperature from a maximum capacity of over 600,000 lb of steam per hour down to less than 150,000 lb per hour. The curve showing furnace outlet temperature required is again enclosed within the burner control zone and reaches to approximately 2200 F for pulverized-coal firing. This is low enough to avoid any slag formation with coals that may be used in this station.

How well this method for control of furnace temperature operates to provide a close degree of steam temperature regulation was shown by a normal 24-day load chart[1] and steam temperature record which was taken from this unit. From 7 a.m. to 10 a.m. the load was practically constant at 450,000 lb per hour and the average steam temperature at the superheater outlet was 900 F with less than ±5 deg F variation. At 10 a.m. the load rose sharply to 540,000 lb per hour and there was a short period of fluctuating steam temperature as the operator manually readjusted the burner tilt to compensate for the change in furnace temperature. Except for the period between 12 noon and 1 p.m. the steam temperature was practically constant at 900 F until the load dropped sharply between 8 and 9 p.m. to 200,000 lb per hour. After burner adjustments were manually made, the temperature was held at 900 F until 5 a.m. when the morning load began to pick up again.

The foregoing data demonstrates that furnace outlet temperature may be selectively controlled over a range of some 200 deg F, from maximum continuous load to some very low-load point. This temperature change is secured manually through a conveniently placed push-button control, which causes the burners to be tilted either upward or downward as may be required. It thus becomes possible, at all times, to operate the furnace of a steam-generating unit, equipped with tilting burners, under conditions which avoid slag accumulations on the heating surface, and yet produce constant superheated steam temperature over a wider range in capacity than by any other direct means now available.

Supplemental use of the gas bypass damper, as a steam temperature trimming device, makes it possible to maintain the variation in superheat within exceeding narrow limits of less than 5 deg F from normal.

[1] Chart reproduced in original paper but here omitted because of space.

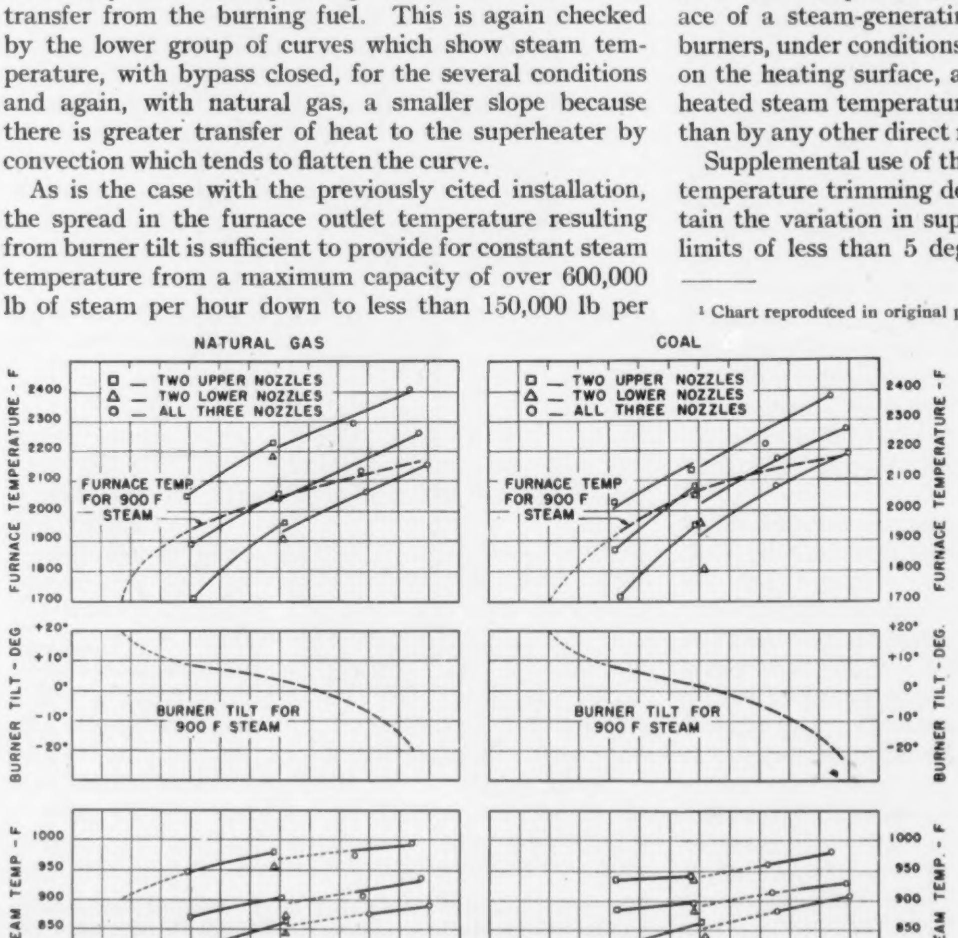


Fig. 9—Effect of burner tilt on furnace outlet temperature and steam temperature obtained with another tangentially fired, dry-bottom unit of 600,000 lb per hr capacity operating at 875 psi and 900 F total steam temperature

Progress in Transformation of Basic Fuels

In this paper presented at Princeton University's Bicentennial Conference, October 2, the author controverts expressed opinions of impending oil shortage by explaining how new synthetic processes for conversion of coal and natural gas to oil have greatly increased our potential oil supplies. There have also been important advances in the conversion of oil into gas. Curves are included showing the relative costs of transmitting these fuels.

By P. C. KEITH

President of Hydrocarbon Research, Inc.

BECAUSE so much has been written concerning our dwindling oil reserves by the National Resources Planning Board, the Department of Interior, the O'Mahoney Committee, and members of the oil industry, most Americans are acutely conscious of what they believe to be an impending oil shortage. There seems to be a general feeling that this country must import additional supplies of petroleum to maintain and expand our present "internal combustion engine economy." While there may be many reasons favoring the importation of petroleum, such importation is not necessary for our national security; and in the foreseeable future might be undesirable both for security and economic reasons.

In the past two decades enormous strides have been made in the production of synthetic fuels both from coal and gas. In 1910 Bergius announced his high-pressure process. In 1927 I. G. Farben built at Leuna the first commercial plant. In the late 20's Franz Fischer announced the Fischer-Tropsch process. In 1934 Ruhr-Chemie installed the first commercial plant at Oberhausen. Beginning in 1939 the mechanized German army, fueled primarily by the 100,000 B/D of synthetic oil produced from coal by these two processes, fought and nearly won a war. It is true that the cost of these synthetic oils was much higher than those produced from petroleum. On the other hand, in the light of present-day American engineering knowledge, the processes used were clumsy and unnecessarily expensive.

The production of oil from natural gas is closely akin to the production of oil from coal. Recently two companies, Carthage Hydrocol, Inc. (a company composed of various units within the oil industry) and the Standard Oil Company of Indiana have announced plans for building two large commercial synthetic oil plants, utilizing dry natural gas as the feed stock. Both these companies expect that the cost of the motor fuel produced will at least be competitive with the cost of motor fuel produced from crude. The prediction has been made that the cost of motor fuel from one of these plants will be $5^1/_4$ cents per gallon. Capital charges represent about 50 per cent and raw material about 20 per cent of this cost. When these plants have a successful performance record behind them and thus allow a reduction in the capital charges the raw material cost could double or treble and cost of fuel made still be competitive with fuel made from crude oil.

Recently H. C. Weiss, president of the Humble Oil and Refining Co., announced that his company was currently considering the installation of a gas synthesis plant. This process can convert our gas reserves into an amount of oil equivalent to our known reserves. The possibility of quickly and economically doubling our oil supplies should be given great weight in predicting our future national economy.

The engineering responsible for this advance in the synthesis of oil was learned in America during the war. Two new techniques were outstanding: (1) the use of the "fluid bed" and (2) the production of cheap chemical oxygen. Both of these techniques can be applied to the synthesis of oil from coal. Before the O' Mahoney Committee in 1943 testimony was presented which showed that oil could be made from coal, using the high-pressure hydrogenation process, at a cost of from 16 to 18 cents per gallon—a cost which is so high as to be of no immediate interest to our oil industry. Recently a major oil company, familiar with hydrogenation, has privately informed me that they now believe that with a "mine-mouth" coal cost of \$2.50 per ton, motor fuel could be produced for between 7 and 10 cents per gallon. My own figures indicate a possible cost of 6.5 cents per gallon, all costs in, with coal at the "mine mouth" worth \$2.00 per ton. This latter figure is competitive with the cost of motor fuel produced from present-day crude oil. When this coal to oil development has been brought to a successful conclusion an important milestone in the transformation of energy will have been passed. The gas to oil conversion process has already materially increased our potential oil supplies but the coal to oil process will cause us to reckon our future supplies by the hundreds of years rather than by decades.

Concurrent with advances made in the synthesis of oil from coal and gas there have been extremely important advances made in the conversion of coal into gas. The Lurgi Company of Germany in 1936 placed into operation at Zettau its first high-pressure coal gas suitable for town use, without using any oil gas for enrichment. The process is simplicity itself. By means of a lock-hopper system, brown coal is fed semi-continuously into the top of an open vessel, suitably insulated, and maintained at a pressure of about 300 psi. Into the bottom of the vessel is fed a mixture of steam and oxygen. By incomplete combustion the coal is gasified, some oil being recovered as a byproduct, and the ash being withdrawn semi-continuously from the bottom. Technically the process has been a great success. At Zittau

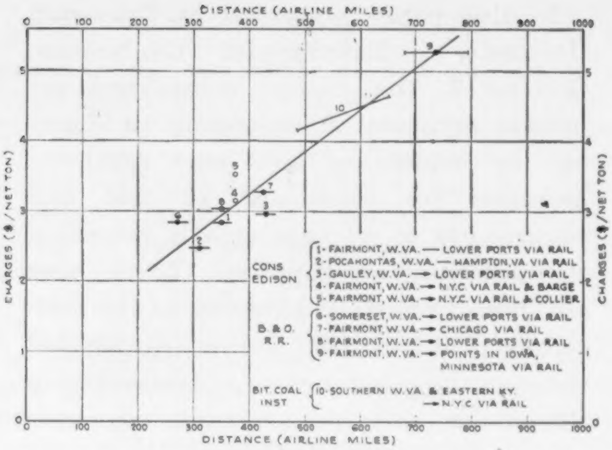


Fig. 1—Cost of transporting coal

the gas made has a calorific value of about 470 Btu per cu ft, when freed of its carbon dioxide content. At Most, Czechoslovakia, I had the privilege of inspecting the last Lurgi installation built. Gasifying brown coal sized from 4–18 mm, they were producing a gas having a calorific value of 570 Btu per cu ft. Had the oil distilled from the coal been returned to the generator for cracking, the calorific value of the gas made would have been in excess of 600 Btu per cu ft. The efficiency of the gasifications step was in excess of 80 per cent,

This installation was supplying gas, at 300 psi pressure, to a 120-mile gas distribution system. A pipe line from Prague to Most is under construction, which will add another 70 miles to the distribution system. Presently, the Lurgi generation plant will be doubled. With the removal of some obvious bottle-necks this installation can produce 15,000,000 cu ft of town gas per day directly from low-grade coal and with a thermal efficiency of over 80 per cent.

As American engineering improved and cheapened the synthesis oil processes, so it can materially improve and cheapen the coal gasification process. Whereas the present Lurgi process utilizes a highly reactive, non-caking brown coal there is no basic reason why a highly caking relatively inactive bituminous coal cannot be gasified to yield a gas of 900 to 950 Btu per cu ft. Development work to achieve this is already under way. The first indications are that it will be successful. Incidentally, our coal reserves are in excess of 3 trillion tons—enough for 2000 years at present consumption rates. Converted to gas this is equivalent to about 60,000 trillion feet—enough to last at the present rate of gas consumption some 1500 years.

So much for the present "state of art" in the transformation field. Oil made in Texas must be used elsewhere. Gas, if made from coal in West Virginia, will be used in more highly industrial areas. The cost of transporting oil or gas has steadily decreased within the past decade. The cost of transporting coal has not shown a corresponding decrease. In my opinion the railroads are not wholly responsible for this lack of improvement. Beset as they are with rate regulatory bodies on the one hand and rather inflexible labor policies on the other they cannot quickly adjust themselves to maintain a competitive position with the ever-evolving and newer means of transportation. In the foreseeable future this inability to adjust themselves may react to their detriment.

The transportation of oil is an example. In 1939 the Class 1 railway average rate, expressed in cents per barrel per 100 miles of straight line distance was 19.78 cents; a comparable rate for pipe lines was 3.92 cents per bbl. The rail rate is some five times larger than the pipe line rate. During the war the operation of the Big Inch and the Little Big Inch showed what can happen to pipe line costs when pipe diameters are increased, pumping equipment is made efficient and largely automatic, and load factor is kept high. A comparable cost for the Big Inch to the ones already given is 1.34 cents per bbl, about $^1/_{15}$ of the rail rate. True, a comparison today of the Big Inch rate with the rail rate is largely academic; but in ten or twenty years it may not be academic, and the trend has been shown. During the war we added 8000 miles to our oil transportation system of which 5000 miles were product lines—lines largely directly in competition with the railroads.

While I haven't specific and precise figures to show the decreasing cost of transporting natural gas when larger diameter lines and higher pressures are used, I am certain that long-range gas transmission costs postwar will be distinctly less than the prewar costs that were applicable to smaller diameter lower pressure lines. A large diameter gas line is being laid from Kansas to California and there is much agitation to convert both the Big Inch and the Little Big Inch to gas service. The private capital responsible for the California line is sure the piping of gas long distances is a cheap way of transporting energy. Bidders for the Big Inch and Little Big Inch are convinced that the use of these lines to transport energy from Texas to New York is economic.

If then, in the future, our main reliance for energy is upon coal and if coal can be economically transformed into gas and oil, it will be interesting to compare the cost of transporting energy as coal to that of transporting an equivalent amount of energy as gas and as oil.

Fig. 1 shows some typical costs of transporting coal by rail and by rail and water. As a specific example,

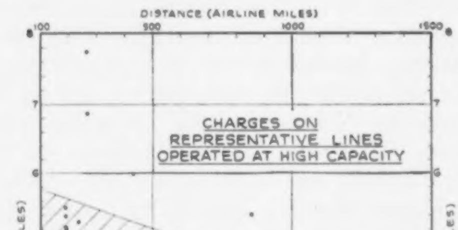


Fig. 2—Cost of transporting crude oil by pipe line

the average cost of transporting a ton of coal from West Virginia to New York City by rail and water is $3.35 per ton—a figure in excess of the mine-mouth production cost of the coal.

Fig. 2 shows an attempt to average prewar pipe line transportation costs. Attention is invited to the cost for the Big Inch. Either at 100 per cent or 67 per cent load factor the experienced costs were much lower than the average. On the assumption that a barrel of fuel oil contains 6,000,000 Btu one may reckon that transporting, by pipe line, the equivalent of one ton of coal from West Virginia to New York will cost 73 cents—a differential between the coal cost and the oil cost of $2.62 per ton. In other words, transporting energy as coal in this particular case costs $3^1/_2$ times as much as transporting the equivalent energy as oil.

Fig. 3 shows the cost of transmitting energy in the form of gas. For our particular case, i.e., transporting 29,000,000 Btu from West Virginia to New York (and in the subsequent discussion a 14,500-Btu coal has been assumed) the transportation cost for gas would be $1.92 vs. $3.35 for coal. Again, there is an incentive for the engineer to develop a process for cheaply gasifying coal and transporting this energy as gas.

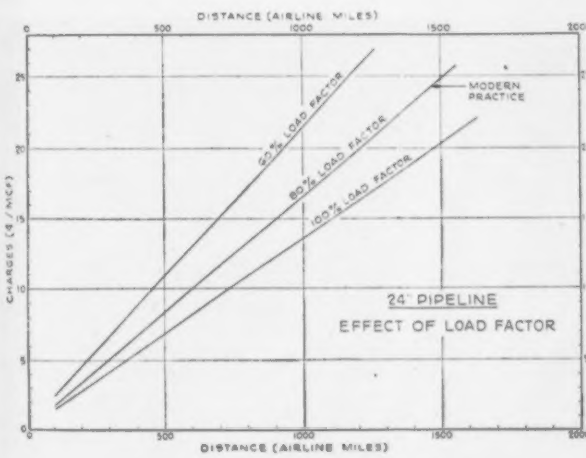


Fig. 3—Natural gas transport charges

Fig. 4 compares transportation costs of the various fuels on a mills per kwhr basis. Since the production of 600-Btu gas is already an established fact, I have shown a curve for the transmission cost of 600 Btu gas (at 80 per cent load factor) from West Virginia to New York. Transportation of this calorific value gas is about a standoff with the transportation of coal, assuming no differential advantage in the use of the gaseous fuel.

However, both gas and oil are a more efficient fuel than coal. While very large high-pressure, high-temperature steam stations may achieve a thermal efficiency of 31 per cent a better average figure would be 28 per cent. On the other hand, either diesels or high mep gas engines can, even in small sizes, achieve an efficiency of 34 per cent. On the assumption that oil and gas could be used with a thermal efficiency of 34 per cent whereas coal would be used at 28 per cent I have constructed Fig. 5 which emphasizes the present-day economics of transporting oil and gas where they are available, with that of coal on a mills per kilowatt-hour basis.

There is every reason to believe that coal may be gasified into high Btu gas with a thermal efficiency of

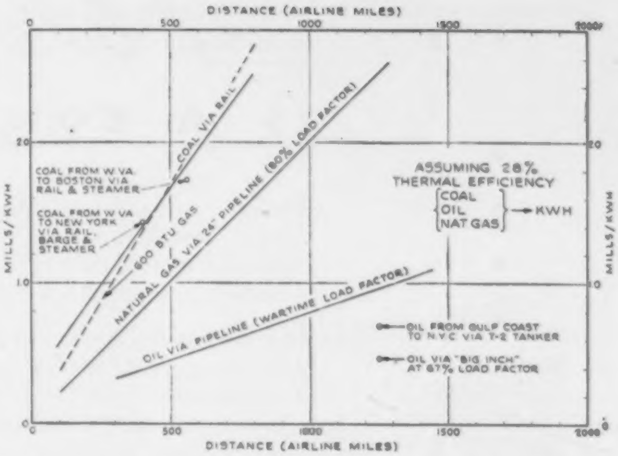


Fig. 4—Cost of transmitting energy in form of coal, oil and natural gas, assuming 28 per cent thermal efficiency

about 80 per cent. Predicted operating costs for such an installation, exclusive of all fuel charges, is about $1.00 per ton. From the figures given here one may reckon that when gaseous Btu's compete on an equal basis as coal Btu's and with coal worth $2.50 per ton in West Virginia, the transportation of a 900-Btu gas begins to look attractive. If allowance be made for the superiority of gaseous fuel when compared to solid fuel the transportation of 700 Btu gas looks attractive.

The figures for transporting coal as oil do not as yet look attractive. Even if coal were $1.00 per ton and allowance be made for this fuel's superiority the figures are disappointing. Again excluding fuel cost, the present predicted costs of transforming a high Btu, low-moisture low-ash coal into oil is over $5.00 per ton or about $1.93 per barrel. Until the capital and operating costs of converting coal to oil can be decreased, coal need have no fear of competition as industrial fuel from oil made from coal. However, gasoline made from coal will in the near future compete with gasoline made from crude.

In conclusion, there is no impending oil shortage; there is impending competition between gas made from coal and natural gas; and there is impending competition between coal moved as gas and coal moved as such.

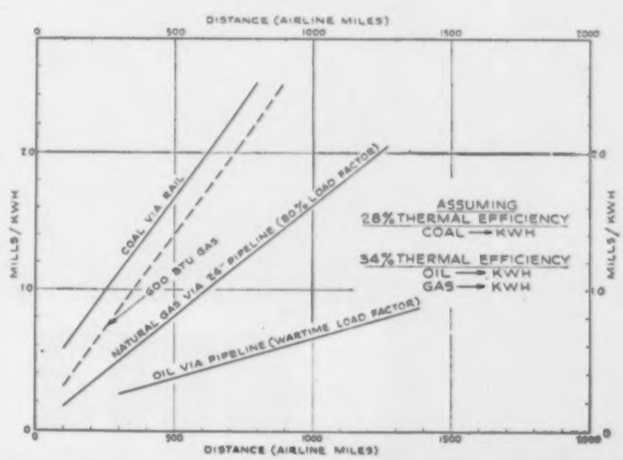


Fig. 5—Cost of energy transmission in form of different fuels at both 28 per cent and 34 per cent assumed thermal efficiency

BETZ *Boiler Water Conditioning*

IS A CONTINUOUS SERVICE

Efficient operation of any steam plant calls for properly controlled combustion, well-maintained auxiliaries and low maintenance. High on the list of important factors that affect efficiency is a complete—and *continuous*—program of boiler water conditioning. Such a service is provided by W. H. & L. D. Betz.

Betz continuing service consists of initial investigation, the establishment of plant control, a daily testing program for boiler room operators, periodic analyses of water samples in the Betz laboratories, frequent engineering reports by Betz engineers on plant operations, and a never-ending program of research.

Over 20 years of experience as water specialists has made the Betz boiler water conditioning service complete . . . economical . . . *continuous*. Our staff of engineers will welcome the opportunity of discussing your boiler water problems.

WRITE TODAY FOR FREE BULLETIN *giving a practical explanation of the phenomena of boiler metal embrittlement (intercrystalline cracking)—a concise discussion of causes, detection and prevention. Ask for Bulletin No. 104—D. W. H. & L. D. BETZ, Gillingham and Worth Streets, Philadelphia 24, Pa.*

BETZ

BOILER WATER CONDITIONING • COOLING WATER CONDITIONING

INDUSTRIAL WASTE TREATMENT

▲ Cover photograph from the *Betz Indicator*, a monthly publication devoted to the chemistry and practical applications of water conditioning. The *Betz Indicator* will be mailed without charge at your request.

American Engineers to Join World Engineering Body

Participation of American engineers in a permanent World Engineering Conference, with headquarters in Paris, was disclosed by C. E. Davies, Secretary of the A.S.-M.E., during the business session of the Society's Annual Meeting. Plans for the Conference were formulated during the International Technical Conference held in Paris in September and the new body will have a practical working contact with the United Nation's Educational, Scientific and Cultural Organization.

The Council of the World Engineering Conference will be made up of not more than three delegates from each participating nation. While the organization is still in a provisional state, the nations which signed up at the Paris meeting were, in addition to the United States, China, Egypt, France, Great Britain, India, Poland, Switzerland and Czechoslovakia. Colonel Aristide Antoine, president of the French union of engineers and technicians, was named president of the executive board, and Fenton B. Turck of New York was named American representative on the board until the formal organization here is completed.

New High in Peak Loads

A new high in aggregate electric utility system peak loads of 40,457,000 kw was attained in October of this year, according to a Federal Power Commission announcement. This was 12.9 per cent higher than the peak for October last year. The wartime maximum was 38,252,630 kw, reached in January 1945. The corresponding energy output for October was 20,187,-843,000 kwhr which represented a gain of 143 per cent over that of October 1945. Combined utility and industrial production was 24,387,917,000 kwhr.

During the month 7,002,721 tons of coal were consumed, of which 6,707,877 tons were bituminous and 294,844 tons anthracite. Fuel oil burned amounted to 3,285,644 barrels, an increase of 12.8 per cent over that of the same month last year.

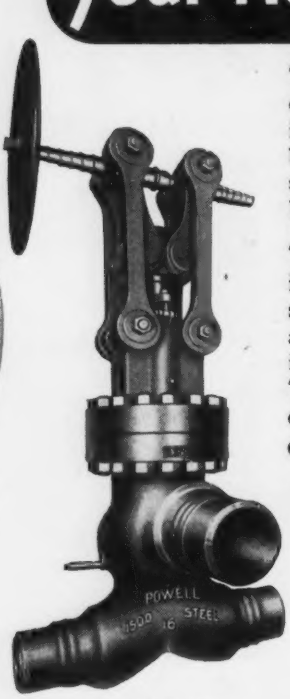
The Power Commission's statistics also show that coal produced 51.6 per cent of the nation's electric energy in 1945; that produced by oil was 3.5 per cent; by gas 8.88 per cent; by wood and waste, 0.08 per cent; and by water power 35.94 per cent.

Water Conference

In our November issue announcement was made of the postponement of the Seventh Annual Water Conference to December 2 to 5, the original date having been cancelled because of the hotel strike in Pittsburgh. However, a second postponement was made largely because of conflict with the data of the A.S.M.E. Annual Meeting and a new date has been set for January 6. The sessions will be held at the William Penn Hotel, as usual, and the extensive program, as previously announced in these columns, will be followed.

POWELL has the *right* Valves for *all* your Flow Control requirements!

Large 125-pound Iron Body Bronze Mounted O. S. & Y. Gate Valve.



Class 1500-pound Cast Steel Non-return Angle Valve, with welding ends. Has a 16" outlet and two 12" inlets. Toggle operated.

This may sound like a broad statement—but we can back it up. Because, through 100 years of making valves—and valves only—Powell has always been ready with valves that are *right*—in both design and material—to meet *all* demands imposed by the amazing growth of American Industry.

Today the Powell Line of Valves for Power Plants includes Bronze and Iron Valves of every necessary type, size, design and working pressure and a complete line of Cast Steel Valves of every type in pressure classes from 150 to 2500 pounds. This includes a number of special designs and an outstanding line of gear, toggle and motor operated Non-return Valves.

200-pound Bronze Globe Valve. Renewable, wear-resisting, semi-cone plug type seat and disc.

The Wm. Powell Co., Cincinnati 22, Ohio

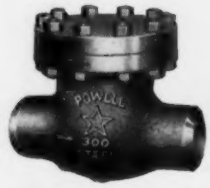
DISTRIBUTORS AND STOCKS IN ALL PRINCIPAL CITIES

Catalogs furnished on request. Kindly state whether you are chiefly interested in Bronze, Iron, or Cast Steel Valves.

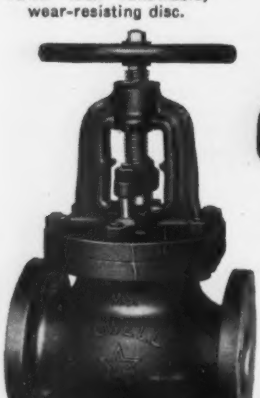
See our exhibit in BOOTH 49 at the 17th National Exposition of Power and Mechanical Engineering. Grand Central Palace, New York City, December 2—7, inclusive.

250-pound Iron Body Bronze Mounted Horizontal Swing Check Valve.

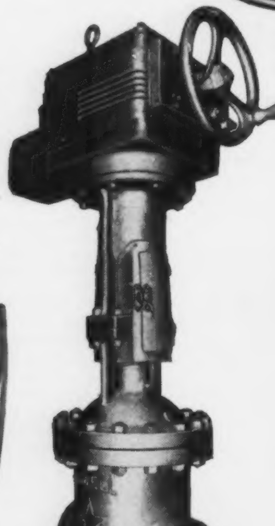
200-pound Bronze Gate Valve with renewable, wear-resisting disc.



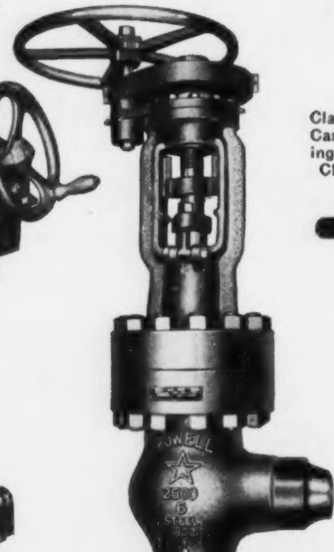
Class300-pound CastSteelWelding End Swing Check Valve.



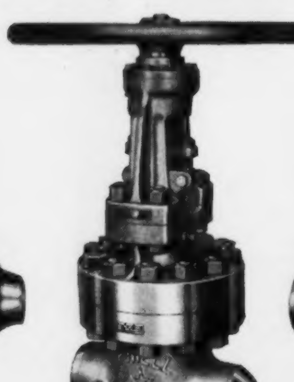
Large 125-pound Iron Body Bronze Mounted O. S. & Y. Globe Valve.



Class 300-pound Cast Alloy Steel Gate Valve with welding ends. Electric motor operated.



Class 2500-pound Cast Alloy Steel, Angle Valve with welding ends. Spur gear operated.



Class 1500-pound Cast Steel Welding End O. S. & Y. Gate Valve.

Class 900-pound Cast Steel Gate Valve with welding ends, welded bonnet, and special by-pass. Bevel gear operated.

POWELL VALVES

Emergency Coal Controls Modified

Relaxing the emergency controls which were in effect during the strike of the United Mine Workers, Solid Fuels Administrator J. A. Krug has issued an interim regulation which will provide necessary stocks for essential users and effect an orderly restoration of the normal flow of coal to other consumers, until there is adequate production to meet all demands.

In order to give every one a fair share of the frozen coal and the coal that will be produced, the new regulation limits receipts on the basis of the consumers supply and requires that the essential users, including householders be supplied before shipments are made to others.

Coal which was destined for export and which was held under the freeze orders, may now be exported if diversions cannot be made without a "back haul." This is necessary in order to free railroad cars which were in short supply for several months before the strike started, and will help alleviate the plight of the liberated nations which have been deprived of coal because of the strike.

Shippers of bituminous coal and commercial dock operators are directed in the new order to give first preference to public utilities which render public service to any community by supplying electricity, water, gas, sewage disposal service or street railway transportation; railroads; steamships and tugboats for bunker and galley fuel; laundries; hospitals; food processing plants (including milk plants, dairies, and commercial bakeries); refrigeration plants; hotels; and retail dealers who supply coal for any of these purposes or for domestic use in any dwelling or apartment. The order limits the amount of coal any of the consumers in the first preference group may be shipped as follows:

1—20 days' supply in the case of any utility, receiving coal all-rail and 30 days' supply in the case of any utility receiving coal via lake, river or tidewater,

2—15 days' supply in the case of any other such consumer receiving coal all-rail; and 25 days' supply in the case of such consumer receiving coal via lake, river or tidewater, and

3—in the case of a retail dealer, or commercial dock operator, a tonnage sufficient to enable him to deliver to each of his consumer customers in the preference group who has less than a 15-day supply on hand, a quantity equal to 15 days' supply or one minimum truck or wagon load.

Midwest Power Conference

Announcement has been made that the next Midwest Power Conference will be held in Chicago, March 31 through April 2. Headquarters as usual will be at the Palmer House and Prof. Stanton E. Winston of Illinois Institute of Technology will serve as Conference Director for the eighth consecutive year. Dr. Edwin E. Whitehead, who has been associated with Duquesne Light Company for the past fourteen years and is now research professor with the Illinois Institute of Technology, will serve as secretary of the Conference.

Personals

Nevin E. Funk, vice president of the Philadelphia Electric Company has been named vice president of the American Society of Mechanical Engineers for Region III to fill the vacancy created by the death of Alexander R. Stevenson.

Allen J. Johnson, until lately associated with the Anthracite Institute has established an office in Lansdowne, Pa., as a fuels and combustion consultant.

Walter R. Keagy, Jr., has joined the staff of Battelle Memorial Institute, Columbus, O., where he will be engaged in research in fuels technology.

Charles F. Codrington has been promoted from assistant sales manager to sales manager of the blower and compressor department of Allis-Chalmers Mfg. Company.

Frederick R. Lack, vice president of Western Electric Company has been elected president of the American Standards Association for the ensuing year.

Lee Mullen has been made general manager of sales for Globe Steel Tubes Company, Milwaukee.

Obituary

L. Lewis Cohen, chairman of the board of the Union Asbestos and Rubber Company, Chicago, New York and San Francisco, passed away at his home in suburban Highland Park, Illinois, October 25, at the age of 55.

REVIEW OF NEW BOOKS

Any of the books here reviewed may be secured through Combustion Publishing Company, Inc., 200 Madison Ave., N. Y.

Elementary Heat Power

By H. L. Solberg, O. C. Cromer and A. R. Spalding

The authors, all of whom are teaching mechanical engineering at Purdue University, have prepared the text with a view to providing an understanding of heat-power equipment and a background for its testing, regardless of whether the student follows with a course in thermodynamics. In fact, the aim is thus to stimulate student interest in thermodynamics through a prior more concrete knowledge of its applications. Emphasis is placed on fuels as sources of energy, the functioning of equipment and its performance.

The sequence of the contents includes matter and energy, fuels and combustion, internal-combustion engines, fuel-burning equipment, steam generation, steam power-plant cycles, steam engines, steam turbines, pumps, fans, blowers, compressors, feedwater heaters, condensers, gas turbines and mechanical refrigeration.

Numerous problems are included and abridged steam tables are appended.

The book contains 480 pages, $8^1/_2 \times 5^1/_2$ in., cloth bound and is priced at $4.75.

Explosion and Combustion Processes of Gases

By Wilhelm Jost

Translated by Huber O. Croft

This text in German was originally prepared in 1935 by Doctor Jost, then professor of physical chemistry at the University of Leipzig. Subsequently, along with many other German texts, it was taken over by the U. S. Alien Property Custodian in 1943. The recent English translation by Professor Croft of the University of Iowa, assisted by Dr. F. L. Fehling of that school, was undertaken to afford American engineers an opportunity to become familiar with certain applications of physical chemistry to the basic theories of combustion as advocated by the author.

The book is primarily a work of reference for those engaged in research in combustion, detonation and explosion, and an idea of its scope can perhaps best be had by enumerating the successive chapters. These are: Initial stages of explosions as a thermal phenomenon; thermal theory of spark ignition; propagation of explosions (including limits of ignition, normal velocity of combustion and influence of mixture); explosions in closed chambers; detonation; flames of gases not premixed; flame temperatures; radiation investigations of flames; kinematics of combustion; combustion of oxygen-hydrogen mixtures and of carbon monoxide; spark ignition; combustion of hydrocarbons (both in the flame and by slow oxidation); the ignition of hydrocarbons at high pressures; and combustion in both the Otto and the diesel cycles.

There are 621 pages including a comprehensive bibliography. The price of the book is $7.50.

Heating and Air Conditioning —6th Edition

By J. R. Allen, J. H. Walker and J. W. James

Textbooks may be good, bad, or just mediocre; this one is excellent and thoroughly up to date. It offers the student or layman a solid theoretical groundwork in domestic and industrial heating and air conditioning and provides him with some knowledge of present practice. The scope and treatment of the subject reflect the high caliber of the authors—John R. Allen, late past president of the A.S.H.V.E., James Herbert Walker, vice president of The Detroit Edison Company, and John William James, research engineer of the Iron Fireman Mfg. Company.

No revolutionary changes have developed since the last edition of this book appeared seven years ago and much of the previous text has been retained. However, numerous additions and changes have been made to both text and illustrations to bring the book into complete accord with recent developments and current practice. The chapter on Fuels and Boilers has been extensively revised, while those on Gravity Warm-Air Furnace Heating and Residence Air Conditioning have been revised to include the latest rating formulas and design procedures of the industry. A new section on panel heating is included and consideration is also given to the principle of a reversed-cycle refrigeration system.

The book is written in a clear and cogent style and covers all the essentials of the subject in 23 chapters, many of which include problems and a bibliography. Hundreds of illustrations in line and halftone support the text and, besides a 13-page Index, valuable reference material is given in a 31-page appendix. The volume comprises 667 pages, size 6 × 9, and is bound in desk green buckram. Price—$5.50.

All the technical and general papers presented at the 1946 Meeting of the Smoke Prevention Association are now available in a leatherette-bound *Proceedings* published by John Paul Taylor, St. Joseph, Mich. The price is $2.

Advertisers in This Issue

Air Preheater Corporation, The........ 11
American Blower Corporation.......... 26
Armstrong Cork Company............ 18
Armstrong Machine Works............ 20
Theo. Audel & Company, Publishers... 47

Bailey Meter Company................ 23
C. O. Bartlett & Snow Company, The.. ....Fourth Cover
Bayer Company, The.............. 16
Beaumont Birch Company............ 63
W. H. & L. D. Betz.............. 58
Bird-Archer Company, The........... 61
Buell Engineering Company, Inc....... 30
Buffalo Forge Company.............. 17

Cochrane Corporation................ 15
Combustion Engineering Company, Inc................ Second Cover, 12 and 13

Dampney Company of America, The... 29
De Laval Steam Turbine Company . 4 and 47
Diamond Power Specialty Corporation.. ....Third Cover

Edward Valves, Inc.................. 5
Engineer Company, The.............. 21
Ernst Water Column & Gage Company.............. 64

Fairmont Coal Bureau................ 27

Grinnell Company, Inc................ 9

Hagan Corporation..............24 and 25
Hall Laboratories, Inc............24 and 25

Infilco Incorporated.................. 8
Ingersoll-Rand Company.............. 10

Northern Equipment Company........ 2

Poole Foundry & Machine Company... 62
Wm. Powell Company, The............ 60
Prat-Daniel Corporation.............. 3

Reliance Gauge Column Company, The. 22
George P. Reintjes Company.......... 64
Research Corporation................ 28

Sauerman Bros., Inc.................. 62
Spang-Chalfant Division, National Supply Company.................. 19
Stock Engineering Company.......... 59

Terry Steam Turbine Company, The... 48

Vulcan Soot Blower Corporation....... 14

L. J. Wing Mfg. Company............. 6

Yarnall-Waring Company............. 7